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Large-scale bioenergy production from soybeans and switchgrass in Argentina Part B. Environmental and socio-economic impacts on a regional level

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ABSTRACT

The feasibility of deploying a socio-economic and environmental impact analysis for large-scale bioenergy production on a regional level is analyzed, based on a set of defined criteria and indicators. The analysis is done for La Pampa province in Argentina. The case study results in conclusions in how far the criteria can be verified ex ante based on available methodologies and data sources. The impacts are analyzed for two bioenergy chains (soybeans and switchgrass) for a set of defined land use scenarios. The carbon stock change for switchgrass ranges from 0.2 to 1.2 ton C/ha/year and for soybean from −1.2 to 0 ton C/ha/year, depending on the scenario. The GHG emission reduction ranges from 88% to 133% for the switchgrass bioenergy chain (replacing coal or natural gas) and from 16% to 94% for the soybean bioenergy chain (replacing fossil fuel) for various lifetime periods. The annual soil loss, compared to the reference land use system is 2–10 ton/ha for the soybean bioenergy chain and 1–2 ton/ha for the switchgrass bioenergy chain. In total, nine sustainability principles are analyzed. In the case of switchgrass, most environmental benefits can be achieved when produced on suitable land of abandoned cropland. Soybean production for bioenergy shows a good overall sustainability performance if produced on abandoned cropland. The production of switchgrass on degraded grassland shows socio-economic and environmental benefits, which is not the case for soybean production. The production of bioenergy production on non-degraded grassland is not preferred. It is concluded that the scenario approach enables understanding of the complexity of the bioenergy chain and the underlying factors influencing the sustainability principles. It is difficult to give ex ante a final conclusion whether a bioenergy chain is sustainable or not as this depends not only on the previous land use system but also on other factors as the selection of the bioenergy crop, the suitable agroecological zone and the agricultural management system applied. The results also imply that it is possible to steer for a large part the sustainability performance of a bioenergy chain during project development and implementation. Land use planning plays a key role in this process.

Contents

Abbreviations: ARG, Argentina; BA, Buenos Aires; C, cropland reference land use system; D, degraded grassland reference land use system; DOM, dead organic matter; EF, emission factor; FT, Fisher Tropsch; G, grassland (non-degraded) reference land use system; GHG, green house gas; HCV, high conservation value; HWP, harvested wood products; LCA, life cycle analysis; NL, the Netherlands; Rdam, Rotterdam; SOC, soil organic carbon; SOM, soil organic matter.

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1. Introduction

Biomass is expected to play an important role in the future supply of modern energy [1,2]. To ensure that bioenergy is produced in a responsible manner, setting principles[1] [3] and establishing certification schemes are possible strategies [4]. Recently, national governments as the UK, the Netherlands and Germany and the European Commission have taken initiatives to develop sustainability principles and biomass certification systems. The need to ensure sustainable biomass production through proper procedures or policy tools is also acknowledged by various international bodies as the G8 Bioenergy Partnership, the WTO, the UNCTAD biofuels initiative and the FAO. In addition, various NGOs and companies have initiated pilot projects, policy papers or initiatives like the Roundtable on Sustainable Biofuels (RSB) to work on a more sustainable bioenergy production chain. Between them, there seems to be general agreement that it is important to include economic, social and environmental criteria when developing a certification system for sustainable bioenergy production.

Concrete initiatives to translate these criteria into operational indicators are, however, limited. Also, many uncertainties on the feasibility and implementation of sustainability principles remain [4]. There are content matters to resolve, like the design of criteria and indicators in accordance with regional requirements, the avoidance of leakage effects, and the influence of land use dynamics on the outcomes of sustainability assessments [4]. Consequently, new standardized methodologies are needed to measure and valuate impacts of bioenergy production [5]. The complexity involved is enhanced by the large number of biomass resources, agricultural production systems, regional settings and conversion routes.

The first objective of this study is to get insights in the feasibility of deploying ex ante a socio-economic and environmental impact analysis on a regional level for large-scale bioenergy production, based on a set of defined principles and criteria. By implementing this analysis for a defined case study, conclusions can be drawn about in how far the criteria can be measured with indicators, based on available methodologies and data sources within a limited time period. The second objective of this study is to analyze the socio-economic and environmental performance of two selected bioenergy chains on a regional level for a defined set of land use scenarios and also to get insight in possible consequences of sustainability principles for the potential of biomass energy and its economic performance on the short- and longer-term.

In this study, a scenario is used as an imagined possible future situation placed in a defined time set.

2. The bioenergy chains and scenario parameters

The impact analysis builds on the results from part A of this paper [6], which evaluated for the La Pampa province in Argentina the potential and cost performance of two defined chains to produce bioenergy for local use or for export. The two chains are summarized here:

I. Switchgrass is cultivated in La Pampa province and, after harvesting, transported as bales by truck to the closest pellet plant. Pellets are exported by truck or train to the harbour Bahiá Blanca. From there, the pellets are shipped to Rotterdam in Europe to be converted into electricity in a power plant in the Netherlands or, alternatively, used in the local market in Argentina [6].
II. Soybean is cultivated in La Pampa province and, after harvesting, transported by truck to Junín for crude soybean oil extraction. After extraction, the crude soybean oil is transported

[1] An important element of a certification system is the definition of standards or principles. Principles define the aim of certification and describe the requirements to be fulfilled for certification. Sustainability principles (e.g. the production of biomass must contribute towards the social well-being of the the local population) are combined with sets of criteria (e.g. no negative effects on human right) that describe the requirements a sustainable product has to fulfil. To use criteria for the formulation of a certification standard they have to be operationalized and measurable. For this purpose, indicators are used. Indicators are measurable parameters (e.g. recognition of Universal Declaration of Human Rights).

by truck or train to Rosario to be converted to biodiesel. The (end)-product is exported by ship to Rotterdam or used in the local market. Alternatively, the crude soybean oil is converted into biodiesel in Rotterdam. [6].

Calculations are done for the potential and costs of the bioenergy chains for the short- and long-term (2030) for the La Pampa province. Calculations for the current situation (CUR) present the performance of the bioenergy chains on the short-term. A set of scenarios present the performance of the bioenergy chains on the long-term (2030). Scenario A assumes a continuation of the current economic development. Scenarios B and C reflect a stronger economic development. Between them, scenario C is more export oriented while scenario B has a more environmental friendly orientation. Scenario C is also more open for competition and the application of advanced technologies. Quantitative scenario parameters that are relevant for assessing the sustainability performance of the bioenergy chains are shown in Table 1. More information on the agricultural production systems and cost parameters assumed for the different scenarios can be found in [6,7].

3. Main characteristics of the selected region

La Pampa is a province of Argentina located in the centre of the country [8], having an area of 134×10^5 ha [9], covered for 7% with annual crops (i.e. wheat, sunflower, maize and soybean), mainly cultivated in the east of the province. More to the west, the land is mainly used for fodder and pasture. The largest part is, however, used for extensive grazing. The agricultural sector contributed 19% to the total GDP of La Pampa in 2006 [10]. The contribution of the livestock sector to this figure was 54% in 2006. A further description of the economic characteristics of La Pampa province is given in [6].

3.1. Biodiversity, flora and fauna in La Pampa province

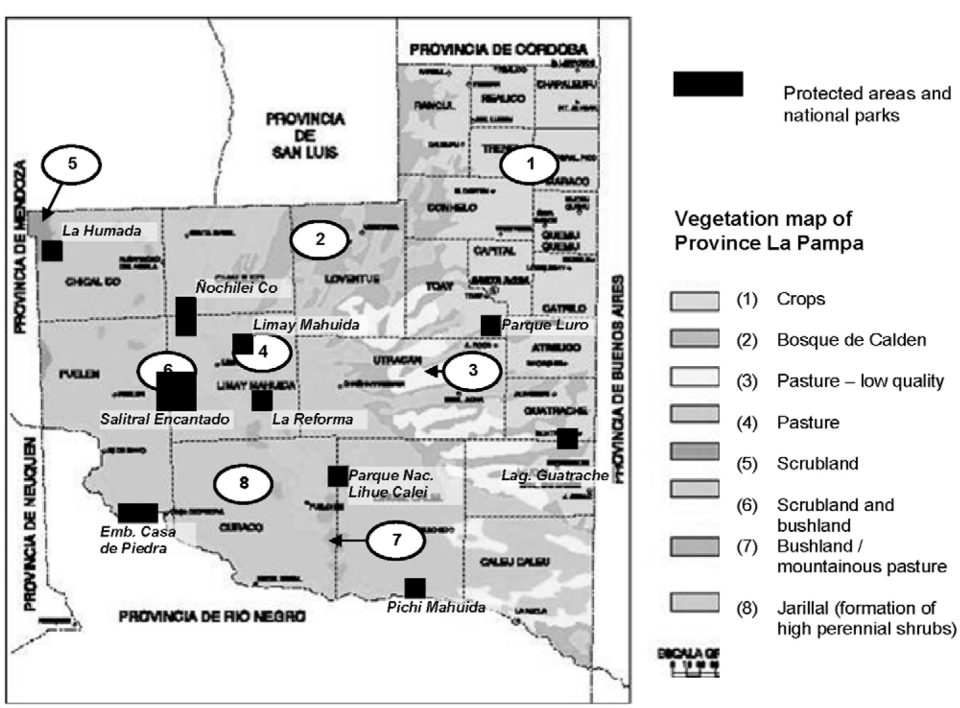
Approximately 70% of La Pampa province is covered by natural vegetation and 30% by annual and perennial crops. The province is characterized by four main vegetation types: Bosque de Caldén, natural pasture lands, shrubs and the Matorral region. The 'Bosque de Caldén', having 2–3 layers of vegetation (trees, shrubs and grasses), is a unique ecosystem in the country. The system is also important because of protection against erosion and its forest production value [11].

The primary economic activity in the 'Bosque de Caldén' is cattle production using natural vegetation. There are a few cultivated pastures or annual crop areas [12]. The total surface of the 'Bosque de Caldén' has diminished significantly in the last few decades because of extraction of trees, expansion of the agricultural frontier forest fires and inappropriate management of nature. Nowadays, the 'Bosque de Caldén' has a total area of around 2870×10^3 ha in Argentina, from which around 750×10^3 ha is suitable for sustainable cattle production or wood logging. The average annual rate of deforestation is around 2700 ha. The average amount of degraded land is around 300×10^3 ha [11]. In the period 1998–2002, the loss of natural grasslands was around 3.6% in La Pampa [13] but area losses of more than 10% are mentioned for other regions in Argentina. Forest exploitation combined with livestock intensification has led to degradation of natural grasslands, resulting in a general decrease of species with a high forage value as well as replacement to species with a lower or no forage value. This process, if continued, can result in severe erosion [14].

The province has six protected areas, covering an area of over 36×10^3 ha (see Map 1), and the National Park Lihuel Cahel [11]. In Argentina 15% of the natural grasslands with a high conservation value (HCV) is protected compared to 4.6% of the natural temporary grasslands worldwide [15]. The protected areas in La Pampa province cover only a small part of its total area (see Map 1). The 'Bosque de Caldén' is protected mainly by Provincial Law prohibiting extraction of native forest species in this area [16]. Other relevant legislations are Laws on the protection of areas [17] and native forests [18].

3.2. Soil types in La Pampa province

The prevailing soil types in La Pampa province can be divided into semi-arid and arid soils. The soil profiles are characterized by sandy

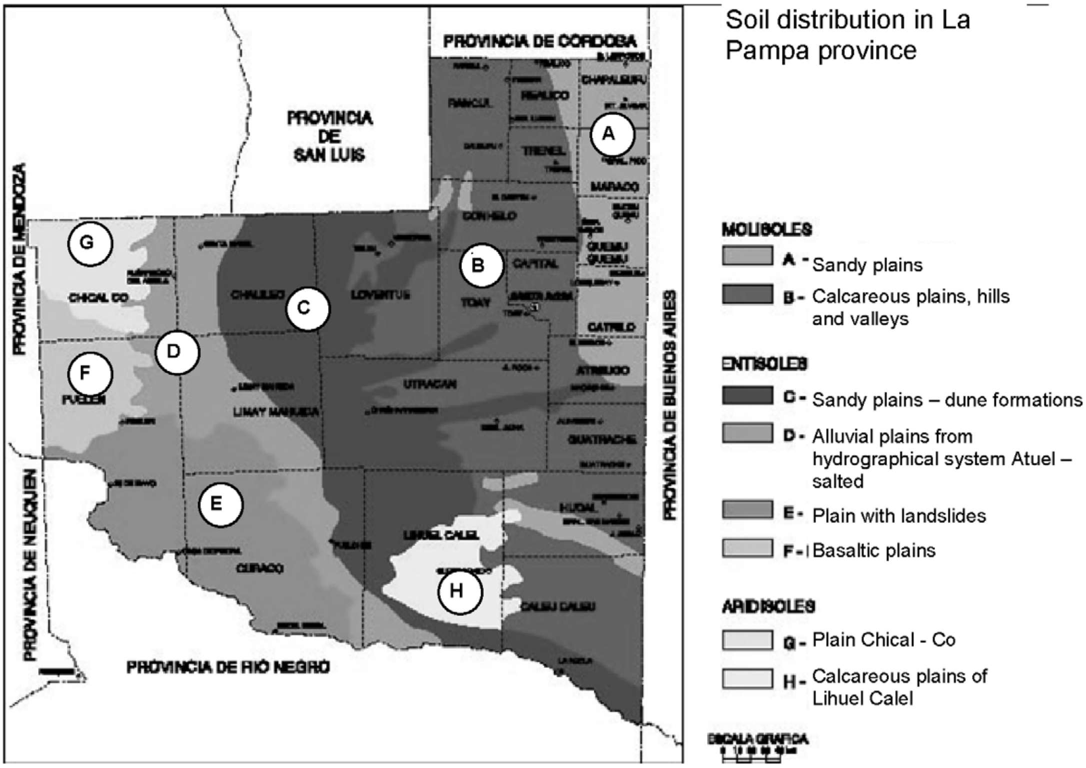


Map 1. Protected areas in La Pampa province based on [12] combined with vegetation map [11]. The Caldenal region is indicated by number 2.

Table 1
Scenario parameters for the current situation (CUR) and for scenarios A, B and C (for the year 2030) on suitable (S) and marginally suitable land (mS), relevant to assess the socio-economic and environmental impact and performance of soybean and switchgrass production in La Pampa province in Argentina.

	CUR		A2030		B2030		C2030	
	S	mS	S	mS	S	mS	S	mS
Reference land-use	Crop production (C)	Degraded grassland (D)	Crop production (C)	Degraded grassland (D)	Non-degraded grassland (G)	Degraded grassland (D)	Crop production (C)	Degraded grassland (D)
Available land for soybean bioenergy production in 10^3 ha	236	61	125	61	238	64	122	45
Available land for switchgrass bioenergy production in 10^3 ha	347	212	161	212	630	171	756	214
Feed conversion efficiency and division feed crops	Pastoral livestock production continues to be important		Pastoral livestock production continues to be important		Increase of mixed/landless production system		Highly intensified livestock management system	
Agricultural production system Switchgrass	- Intermediate agricultural production system - No irrigation - Lifetime plantation: 15 years - No-tillage system		- Intermediate agricultural production system - No irrigation - Lifetime plantation: 15 years - No-tillage system		- Mixed agricultural production system - No irrigation - Lifetime plantation: 20 years - No-tillage system		- High input agricultural production system - No irrigation - Lifetime plantation: 17.5 years - No-tillage system	
Agricultural production system Soybean	Direct seeding, intermediate input system, reduced tillage		Conventional cropping system (no direct seeding), reduced tillage		Direct seeding in combination with other conservation measures, no tillage		Direct seeding, advanced technologies to improve efficiency, reduced tillage	
Yield soybean in tdm//ha	2.1	1.3	3.1	1.9	3.2	1	3.5	2.3
Yield switchgrass in tdm/ha	10	5	13.2	6.6	14.6	7.3	16.7	8.3
Environmental and economic priorities	Average environmental awareness due to economic constraints. Protection of the internal market and local producers		Average environmental awareness due to economic constraints. Protection of the internal market and local producers		High environmental awareness. Diversification of landscape and renewable energy sources is promoted		Low to average environmental awareness. Economic growth is priority. Competition on the internal market	
Technology level applied	Processing plants (e.g. pellet plant) are used on a small scale		Processing plants are used on a small scale		Making use of larger processing plants available in Latin American region		Up-scaling of processing plants. Making use of state of the art technology	
Land rent switchgrass[a] (US$/ha/year)	130	110	195	110	124	121	111	110
Land rent soybean[a] (US$/ha/year)	150	130	225	163	150	130	225	195

[a] Current land prices in Argentina are high, also in comparison with other countries [7]. Land rent fluctuates largely in Argentina per region and per land-use. The future land rents are based on the availability of S and mS land for bioenergy production and on the expected price trends for switchgrass and soybean and their end-products, see also [6].



Map 2. Distribution of the soils in La Pampa province, [11].

to loamy-sandy soils with little to average organic matter content and moderate to high sensitivity for wind and water erosion. This sensitivity increases to the west where rainfall is less [11]. The so-called Molisols, also classified as Kastanozem soil [19], cover 66×10^5 ha of the province. Within the Molisols, a further differentiation can be made into soil type A and B (see Map 2). The land use on soil type A, the '*sandy plain*', is characterized by a mix of agricultural land use. Crop production dominates over cattle production. Although these lands have a low sensitivity to erosion, there are signs of severe erosion in the past. The rest of the *sandy plain* is represented by less developed soils, sensitive for wind erosion, with good permeability and average fertility. In these areas, agricultural land use is mixed. Cattle dominates over agriculture [11]. The second soil type B is the '*calcareous plains, hills and valleys*'. These soils are drier than the soils in the arid plains and developed from mid-sandy to sandy sediments. The majority of the soils present a gradient of average erosion because of its characteristics (limestone content, drier) and because of overuse from grazing. Several locations show severe erosion [11]. The province has introduced a program 30–40 years ago to promote the establishment of Weeping Lovegrass to improve the quality of the soil in eroded areas. This is an area of around 3×10^5 ha [20]. A disadvantage of this grass species is, however, its low forage quality [21].

3.3. Water resources in La Pampa province

The province has limited superficial water sources. The Rio Colorado, with a basin of 70×10^5 ha, forms the southern border of the province. The second main river (Salado-Chadileuvú) goes from north to south in the west of the province and is characterized by various tributaries and lakes. The water quantity of the latter is deteriorating due to overuse of the water upriver in its side rivers. There are some lakes in the province. A drying process is noticed at most of the lakes and some of them have disappeared. In the west of the province, some salty lakes can be found [11]. Also, the continental climate of the region with a wide thermic range promotes evapotranspiration, with negative results for the water balance in the soil, especially in the west.

There are eight aquifers in the region with an area ranging from 7×10^3 to 160×10^3 ha [11]. Most of them are located in the east-centre of the province and are replenished during periods of rain. The hydrochemical composition of the water varies within and per aquifer, depending on the hydrogeology of the area [22]. Consequently, potable water is available in some of the aquifers [11]. The water in other aquifers shows, however, higher salinity levels than allowed for human consumption [22].

3.4. Climatic characteristics of the region

Average annual temperatures in La Pampa province range from 16 °C in the north-west to 14 °C in the west. Average temperatures range between 7 and 8 °C in July to 22–24 °C in January [23]. In the last 70 years, the climatic pattern in La Pampa province is changing to a higher variability of rainfalls, lower maximum and higher minimum temperatures and a reduction of frost periods. This situation of inter-annual instability is expected to increase in the future [24].

The centre of La Pampa province receives around 500 mm of rain a year, diminishing towards the west. Low humidity results in high contrasts of temperature between day and night. Most rain falls in the months September to November and February to March [25]. There is limited rainfall from May to August. Although the precipitation is low in winter time, it is usually adequate (due to low temperatures) for agriculture although it can be too limited for double-cropping systems. There are intermittent shortages of water in the summer months from two to six weeks, especially in January and February, which can be devastating to summer crops [26].

3.5. Socio-economic characteristics of the region

The average population density in the province increased in the period 2001–2006 from 2.1 to 2.27 habitants (hab.) per km^2. The eastern part of the province (around 3 hab./km^2) is more densely

Table 2
Summary of the Dutch framework for sustainability principles: the corresponding criteria, indicators and minimum requirements defined per criterion are not reported here. For details: see [30].

Principles	
1	Biomass production must not be at expense of important carbon sinks in vegetation and in soil.
2	The GHG balance of the production chain and application of the biomass must be positive
3	Biomass production for energy must not endanger food supply and local biomass applications
4	Biomass production must not affect protected or vulnerable biodiversity
5	Soil and soil quality must be retained or even improved.
6	Ground and surface water must not be depleted and its quality must be maintained or improved.
7	In the production and processing of biomass the air quality must be maintained or improved.
8	The production of biomass must contribute towards local prosperity.
9	Biomass production must contribute towards social well-being of employees and local population.

populated. More to the west, the average population density is 1.3 hab./km^2. The rural population represents 23% of the total population in 2001 compared to 35% in 1991 showing a tendency towards urbanization [27].

The unemployment rate in La Pampa province was on average 11% in the 1st semester of 2006, which is in line with the average unemployment rate in Argentina for that year [28]. The under-employment rate[2] in La Pampa province in that period was 7.5% [28]. According to Verner [27], only 20% of the household heads in dispersed rural areas are engaged in the formal labour market while 80% is engaged in the informal labour market. In 2003, more than 75% of the extreme poor households cited agriculture as their primary form of employment. The census from 2001 shows that in La Pampa province 9% of the interviewed private households have insufficient means to facilitate their basic needs [10].

The total number of agricultural units in La Pampa province has decreased with more than 10% in the period 1998–2002. The number of small agricultural units has decreased while the amount of larger (>500 ha) agricultural units has increased [29]. The dominating size of agricultural units for cultivated land was 200–1500 ha (52%) in the period 1998–2002, while 12% had a surface area of 5×10^3 to 20×10^3 ha. For perennial fodder, 37% of the agricultural units have a surface area of 200–1500 ha and 21% has a surface area of 5×10^3 to 20×10^3 ha [29]. The most common form of agricultural land ownership in La Pampa province is private ownership (64%), followed by land tenure (19%) and other forms of tenureship. Agricultural units are mainly privately owned (59%), followed by different forms of cooperatives (39%). A small percentage of the agricultural units (2%) is owned by governmental organizations or NGOs [21,28].

4. Environmental and socio-economic performance of bioenergy chains

As already indicated, there are various initiatives to develop principles, criteria and indicators to measure and evaluate the environmental and socio-economic performance of bioenergy chains [4]. In this study, the performance will be analyzed based on a testing framework developed by the Dutch project group 'sustainable production of biomass' [30]. This framework is at this moment one of the most extended ones, covering most of the principles also proposed in other initiatives. The principles used in this framework, nine in total, are shown in Table 2. They are discussed and applied for the La Pampa province in the following sections. At the end of each section, a conclusion is given about the relative performance of the bioenergy chains for the principle discussed.

4.1. Principle 1: biomass production not at expense of carbon sinks

This principle states that the possible increase of GHG emissions, as a result of soil carbon changes due to the cultivation of areas for biomass energy production, must be neutralized by the reduction of GHG emissions from the biomass production chain. Areas in which the loss of above-ground carbon storage cannot be recovered in a ten year period of biomass productivity as well as areas with great risk of significant soil carbon losses are excluded [30]. Annual carbon stock changes are calculated according to the IPCC approach [31] as recommended by [32,33]. The IPCC approach uses a three-tier approach distinguished by its required data input. Due to limited availability of local data on soil carbon stocks, the Tier 1 approach (basic data inventory) is used for this study. The carbon stock change for a land use category is defined as the sum of changes from above-ground biomass, below-ground biomass, dead organic matter (DOM), soils and harvested wood products. The latter is not relevant for the selected case studies. DOM stocks are zero for non-forest land use categories under Tier 1 [31]. The annual carbon stock change, based on an average Molisol (see also Table 3), is therefore [31]:

$$\Delta \mathrm{Clu} = \Delta \mathrm{Cab} + \Delta \mathrm{Cbb} + \Delta \mathrm{Cso} \tag{1}$$

where: ΔClu is the total carbon stock changes; ΔCab is the carbon stock change in above-ground biomass; ΔCbb is the carbon stock change in below-ground biomass; ΔCso is the carbon stock change in soils.

ΔCso is calculated with formula 2.24 from IPCC.[3] The net flux for inorganic C stocks is zero under the Tier 1 approach [31]. Drained organic soils (peat derived soils) are not present in the selected region and annual changes in carbon stocks are therefore zero. The annual change in carbon stocks in below- and above-ground biomass is based on the stock-difference method [31]. The available above-ground biomass is the sum of total above-ground biomass minus the harvested yield and the removal of a percentage of the residues. The remaining amount of residues is available for decay and to build up soil organic matter. The following formula[4] is used to calculate the available above-ground biomass:

$$G(\mathrm{above}) = \left\{ \frac{Y_{\mathrm{calc}}}{\mathrm{HI}} - (Y_{\mathrm{calc}}) \right\} \times F_{\mathrm{man}} \tag{2}$$

where: G (above) is the available above-ground biomass in tdm/ha year; Y_{calc} is the calculated yield in tdm/ha year; HI is the harvest index[5] (dimensionless); F_{man} is the management factor in % for leaving residues on ground (dimensionless).

[2] Underemployment rate: proportion of employed persons who expressed desire to have additional hours of work in their present job or in an additional job or to have a new job with longer working hours. An additional 2.1% of the proportion of employed persons in La Pampa province is underemployed but have no desire for additional hours of work.

[3] $\Delta C_{\mathrm{soils}} = \Delta C_{\mathrm{mineral}} - L_{\mathrm{organic}} + \Delta C_{\mathrm{inorganic}}$, where Δ is annual change, C_{soils} is carbon stocks in soils, C_{mineral} is organic carbon stocks in mineral soils, L_{organic} is annual loss of carbon from drained organic soils and $C_{\mathrm{inorganic}}$ is inorganic carbon stocks from soils.

[4] IPCC provides default values for annual crops and forestry to calculate $G_{(\mathrm{above})}$. As default values for switchgrass (and perennial grasses in general) are not available, own calculated data are used.

[5] Harvest index is the ratio of yield biomass to the total cumulative biomass at harvest.

Table 3
Default values used for calculating carbon stock changes based on [31], based on [34] if * is indicated in the table. Default values are calculated based on [35] if ** is indicated in the table.

Indicator	Default value
Climatic region	Warm, temperate, dry
Soil type	HAC soils (including Molisols)
Ecological zone	Subtropical steppe
Time dependence period	20 years (in line with rotation period switchgrass scenario B)
Management practice reference land-use on suitable land (S) area	CUR: Cropland, intermediate input, reduced tillage (C) Scenario A: cropland, intermediate input, reduced tillage (C) Scenario B: non-degraded grassland (G) Scenario C: cropland, high input, reduced tillage (C)
Management practice reference land-use on marginal suitable land (mS) area	CUR: degraded grassland, unimproved (D) Scenario A: degraded grassland, unimproved (D) Scenario B: degraded grassland, unimproved (D) Scenario C: degraded grassland, unimproved (D)
Management practice current soybean biomass chain (for S and mS land)	CUR: cropland, intermediate input, reduced tillage Scenario A: cropland, intermediate input, reduced tillage Scenario B: cropland, intermediate input, no tillage Scenario C: cropland, high input, reduced tillage
Management practice current Switchgrass biomass chain (for S and mS land)	CUR: grassland, non-degraded Scenario A: grassland, non-degraded Scenario B: improved grassland Scenario C: improved grassland
Carbon fraction (CF) annual crops	0.47 ton C/tdm
Carbon fraction (CF) grassland	0.5 ton C/tdm
Management factor $F_{(\mathrm{man})}$	50%
Harvest index grassland systems*	0.5 for intermediate input system 0.65 for high input system
Harvest index soybeans*	0.23 for intermediate input system 0.30 for high input system
Below-ground/total biomass grassland	74%
Below-ground/total biomass soybeans**	≈12%
Stock change factor land-use (F_{lu})	0.58 ± 61% for cropland 1 for grassland (for all permanent grassland)
Stock change factor for management regime (F_{mg})	1.09 for reduced tillage cropland system 1.17 for no-tillage cropland system 0.97 for moderately degraded grassland 1 for non-degraded grassland 1.17 for improved grassland
Stock change factor for input organic matter (F_{i})	1 for medium input cropland 1.37 for high input cropland 1 for medium input grassland
Defined area	Calculated for 1 ha

The calculated bioenergy crop yields are shown in Table 1 [6]. It is assumed that the plant, cultivated on the reference land use 'cropland' (C), is soybeans. Corresponding yields are shown in Table 1 for the current situation and for scenarios A, B and C for 2030. The yield levels for the reference land use 'non-degraded grassland' (*G*) correspond with the yield levels for switchgrass. It is assumed that the yield levels for the reference land use 'degraded grassland' (D) are 50% of the yield levels for non-degraded grassland. The data sources used for the calculation of formula (1) and (2) are shown in Table 3 [31,34,35].

A key precondition in the assessment of the potential of bioenergy in La Pampa province, under various scenarios, is that food and feed demand is met [6]. Leakage is thus explicitly avoided in the scenarios. A crucial point in the current debate around the net GHG impact of biofuels is induced land use changes. Recent studies [36,37] have debated that including GHG emissions from indirect land use could drastically worsen or even revert the GHG emission balance of energy crop production mainly due to soil carbon stock changes. How to include GHG emissions from indirect land use changes in the calculation of GHG balances and soil carbon stocks is still under debate [38]. One proposal [39] is to make use of a so-called "risk adder" as not every increase of biomass leads automatically to indirect land use change. The risk adder (or a range) therefore describes an average share factor (in %), which is adopted for land use change to get an indication of its impact on total carbon stock changes. Assume, for example, that half of the total biomass production (100 ha) is produced on abandoned cropland (50 ha) and the other half is produced on areas inducing displacement (50 ha). The risk adder in this example is 50%, which means that the carbon stock change from indirect land use change is calculated for 50% (50 ha) of the total land area. In this study, two alternative scenarios (ALT) are defined to look at the consequences of leakage on the carbon stock changes based on the risk adder approach [39], using a risk adder of 25% and 50%, respectively. The ALT scenarios assume that the production of the previous land use system, cropland, in (CUR-S-C) is partly displaced to an area not yet in use, which is natural grassland. To calculate the carbon stock changes due to this indirect land use change, it is assumed that the yield for natural grasslands with limited management is 80% of the yield for non-degraded grassland.

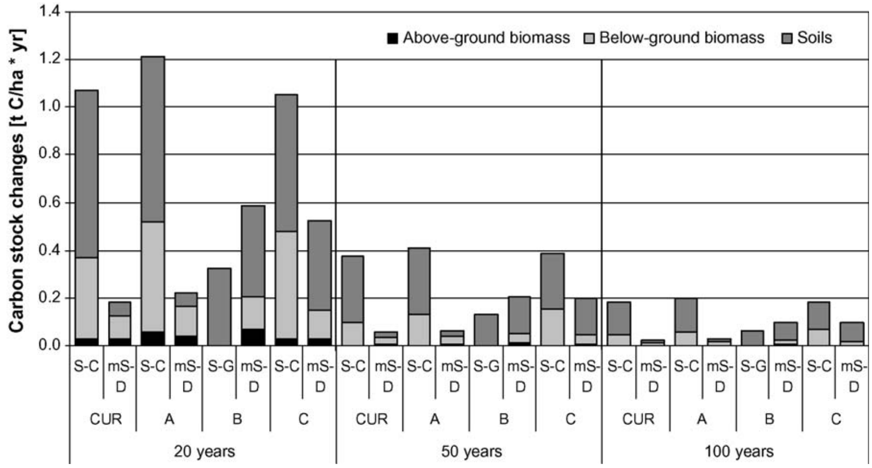


Fig. 1. Carbon stock changes for switchgrass in current situation and for scenarios A, B and C for year 2030, for different lifetime periods (20, 50 and 100 years) combined with different HI (50 years: HI = 0.7–0.75 for switchgrass and 0.3 for soybean, 100 years: HI = 0.8–0.85 for switchgrass, 0.4 for soybean.

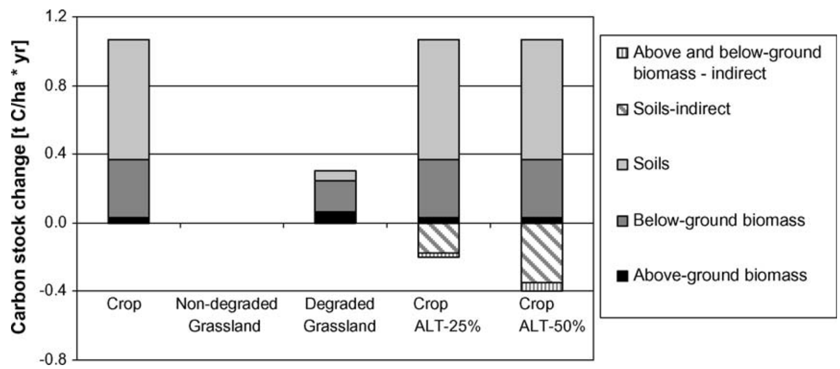


Fig. 2. Carbon stock changes for switchgrass production in (CUR-S) for different reference land-use systems (crop, non-degraded grassland and degraded grassland) and for the alternative scenarios (ALT), including the effect of indirect land use change with a risk adder of 25% and 50%, assuming a lifetime period of 20 years.

4.1.1. Carbon stock changes in the switchgrass bioenergy chain

The carbon stock changes for the switchgrass production system are calculated in ton C/ha year with a lifetime period of 20 years for the different scenarios. Fig. 1 shows that the current situation and scenarios A, B and C have a carbon benefit for switchgrass production compared to the reference land use system ranging from 0.2 to 1.2 ton C/ha/year. The scenarios (CUR-mS-D,[6] A-mS-D) have the lowest carbon benefits because of lower yields and limited differences with the land use reference system. The soil carbon changes determine largely the total carbon stock changes (see Fig. 1) for almost all scenarios, except for (CUR-mS-D, A-mS-D).

The soil carbon stock benefit in scenario B can be explained by the difference in management factor (see Table 3) between the reference land use and the switchgrass production system. Lewandowski et al. [40] confirm the influence of soil carbon on total carbon benefits for switchgrass production after land use change, mentioning that switchgrass stores a considerable amount of carbon in the soil by increasing the humus content and by the formation of high amounts of subsoil rhizomes. The deep, productive roots of switchgrass cause an increase of the soil organic carbon (SOC) content [41]. Consequently, switchgrass is a bioenergy crop with the potential to increase soil C sequestration [42]. Fig. 1 shows that the carbon stock benefit for switchgrass production diminish to lower, although still positive, values when a longer lifetime period is assumed combined with a higher value of the harvest index.

The influence of different reference land use systems and indirect land use is shown in Fig. 2 for (CUR-S-C). In case Switchgrass production replaces non-degraded grassland, carbon benefits are zero as yields and soil carbon accumulation are assumed to be similar. Most benefits are achieved when cropland is replaced, followed by degraded grassland. Regional data from La Pampa province [43] confirm the IPCC results with field data on root carbon content. The highest SOC content is found on the switchgrass field followed by forest land and cultivated land with root contents of 6760, 5760 and 420 kg/ha, respectively. Similar results are found in the USA [41,44].

In [44], it is estimated that 182 ton CO_2/ha is mitigated and 1.8 ton CO_2/ha is released by SOC when switchgrass replaces annual arable cropping in the USA. In case switchgrass replaces permanent grassland, no CO_2 is mitigated by SOC and 1.8 ton CO_2/ha is released, showing more negative results than the outcomes for scenario (B-S-G). Mind that the results for carbon stock changes with reference land use ‘grasslands’ are more positive than the results found by Bullard and Metcalfe [44], possibly because this study uses the same yield levels for switchgrass production and for the reference land use ‘grasslands’ (see Section 4.1.1).

The two alternative scenarios in Fig. 2 show that an indirect land use change in scenario (CUR-S-C) results in a carbon loss due to changes in soil carbon, as well as the amount of above- and below-ground biomass.

[6] The scenarios are presented by (in this order): (i) indicator for scenario or current situation (CUR, *A*, *B*, *C*); (ii) their land use (mS or S land) and (iii) their reference land use (*G*, *D* and *C*). See also Table 1.

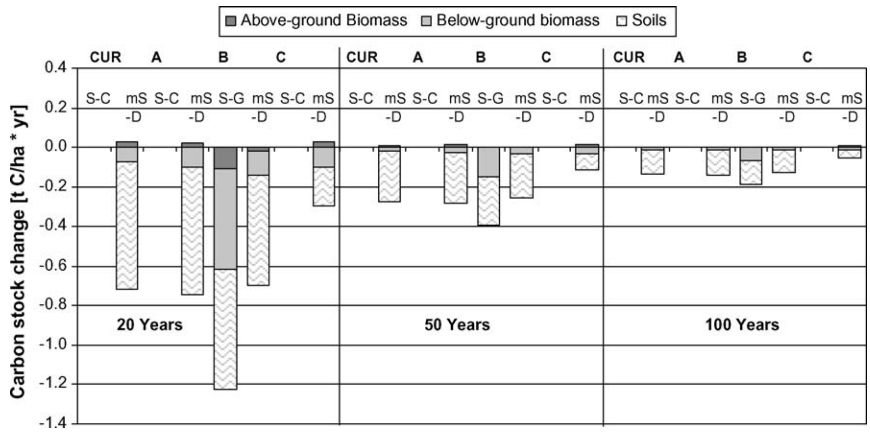


Fig. 3. Carbon stock changes in ton C/ha/year for soybean for current situation and for scenarios (A, B and C) to 2030 for different lifetime periods (20, 50 and 100 years) combined with different HI (50 years: HI = 0.7–0.75 for switchgrass and 0.3 for soybean, 100 years: HI = 0.8–0.85 for switchgrass, 0.4 for soybean).

Based on the results, a conclusion is given about the relative performance of the switchgrass bioenergy chain for this principle, based on a lifetime period of 20 years. The highest score (++) is for the scenarios with a carbon benefit of 0.6 ton C/ha/year or more within a period of 20 years. This score is achieved when switchgrass is produced on *S* land replacing abandoned cropland in CUR and in scenarios A and C. Relative high scores (+), with a carbon benefit of more than 0 and less than 0.6 ton C/ha/year, are achieved in scenarios where degraded grassland is used for switchgrass production and in scenario (B-S-G).

4.1.2. Carbon changes for the soybean bioenergy chain

The carbon stock changes are also calculated for the soybean production systems assuming a lifetime period of 20 years. The outcomes for the different scenarios show a range of −1.2 to 0 ton C/ha/year compared to the reference land use. There are no changes in carbon content when soybean production replaces abandoned cropland. There is a carbon loss when soybean production replaces degraded and especially non-degraded grassland. The decrease in soil carbon can mainly be attributed to the difference in the IPCC default values for land use (Flu) between grassland and cropland (see Table 3). The influence of the management system (Fmg) on soil carbon changes is limited as it is assumed that within one scenario both the reference and biomass production system practice the same kind of management. The negative carbon stock changes for soybean bioenergy production (whole crop) reduces when a longer lifetime period is assumed (the total carbon stock change is distributed over a longer time period) combined with a higher value of the harvest index (Fig. 3).

Fig. 4 demonstrates the influence of different reference land use systems, management systems and indirect land use change on carbon stock changes for one scenario (CUR-S-C). Replacing non-degraded or degraded grassland by soybean production, results in a carbon loss. The decrease in soil carbon content of cropland shifting from (natural) grassland is mentioned, among others, by Zach et al. [45]. This study in La Pampa province demonstrates that the highest C concentration was found under the natural Caldén savannah. Conversion of C_4 pasture to arable land caused a 33% reduction in the total topsoil carbon content after 13 years of conventional tillage. A second site showed that a 10–13 years cultivated crop area that replaced C_4 pasture land, lost 38–61% of its former C_4 carbon content after 10–13 years of cultivation of C_3 crops.

Shifting from a reduced to a no-tillage system results in a net carbon stock benefit (see Fig. 4) assuming all other factors remain constant. This is confirmed by a study located in the west of Buenos Aires [46]. Similar results are found for other sites in the region. Several researchers in Argentina have mentioned that IPCC standards hardly distinguish differences between agricultural practices commonly used in Argentina and more research is needed to get better insight in the impact of different agricultural systems on the net total GHG emissions [47,48]. Fig. 4 shows that indirect land use change from soybean production has an impact on the total carbon stock results changing the carbon balance from zero in (CUR-S-RT) to −0.5 ton C/ha/year when a risk adder of 50%

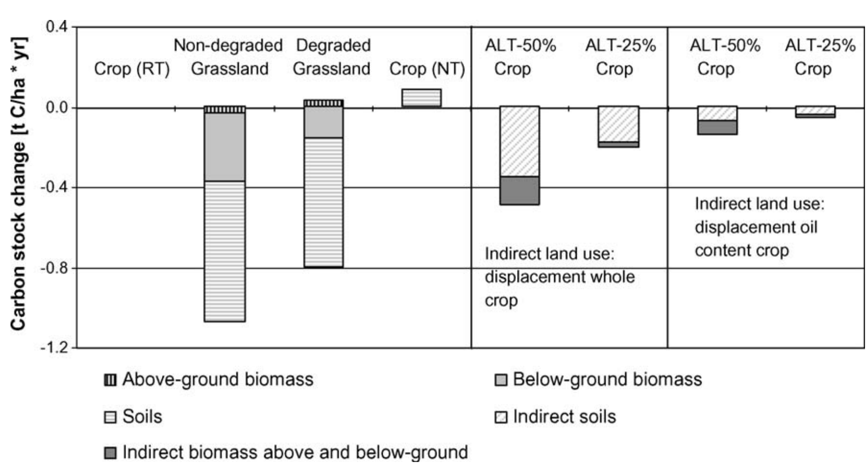


Fig. 4. Carbon stock changes from soybean production in current situation (CUR-S) for different reference land-use systems (crop, non-degraded grassland and degraded grassland), management systems (RT = reduced tillage, NT = no tillage) and for alternative scenarios (ALT), including indirect land use change with risk adder of 25% and 50%, assuming a lifetime period of 20 years.

is assumed. Mind that this risk reduces significantly when it is assumed that the feed (80% of whole crop) generated during soybean production is used to reduce the pressure on land use conversion (see also Sections 4.3 and 4.4).

Based on the results, a conclusion is given about the relative performance of the soybean bioenergy chain for this principle, based on a lifetime period of 20 years. The lowest score (–), with a carbon loss of 0.6 ton C/ha/year or more, is estimated for the scenarios where degraded grassland is used for soybean production and for scenario (B-S-G). No scenario has a negative score, with a carbon loss of 0.6–0 ton C/ha/year. The scenarios in which soybean bioenergy production replaces abandoned cropland (CUR-S-C, A-S-C, and C-S-C) have a neutral score. A small positive score could be obtained in case crop management improvements (as no tillage) are made compared to the reference management system. Leakage should strongly be avoided as this result in significant carbon stock losses.

4.2. Principle 2: GHG balance of bioenergy chains

The principles of Cramer et al. [30] request a minimum GHG emission reduction of at least 30% for transportation fuels and of at least 50–70% (still under debate, the threshold of 60% is used in this study) for electricity. The European Commission [49] has agreed on a GHG emission reduction requirement of 35% for biofuels and this threshold will be further used in this study. The European Commission proposes to increase the threshold of 35–50% in 2017. Cramer et al. [30] also considers to make this criterion stricter on the longer-term, suggesting a GHG emission reduction requirement of at least 80–90% (the threshold of 85% is used in this study).

The GHG calculation for the bioenergy chains is based on LCA methodology as suggested by [32,33,39,49,50] and accounts for all GHG emissions that arise between initial land use conversion up to the final use of bioenergy. The percentage of GHG emission reduction is calculated by dividing the difference in GHG emissions from the fossil and bioenergy chain divided by the emissions of the fossil reference system [51].

The three most important GHGs, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are included in the calculation. For comparing the impact of the three gases, the concept of global warming potential (GWP) is applied following the guidelines of IPCC (GWP CH_4 = 21 and GWP N_2O = 310 compared to CO_2). Other GHGs are not taken into account as they are insignificant in the bioenergy production chains [32,33].

Nitrous oxide (N_2O) is produced in the soil from nitrogenous fertilisers and from natural mineralisation of nitrogen, by the parallel processes of bacterial nitrification and denitrification [52]. In this study, N_2O emissions are calculated with the Tier 1 methodology from IPCC [31]. It must be noted that the IPCC methodology (Tier 1) largely ignores the variability of emissions caused by differences in environmental conditions, crop type and agricultural management system [53]. The default values from [31] indicate therefore a broad range of data insecurity. However, due to lack of more precise input data for the selected region, the IPCC approach is used for the calculation of direct and indirect N_2O emissions for the biomass system and the reference land use system, as also suggested by [32,33,54].

Table 4
Key input data and references for calculating the GHG emissions of the switchgrass and soybean bioenergy chains for the current situation and for scenarios A, B and C to 2030.

General input data	Unit	Emissions				Reference
		CO_2	N_2O	CH_4	CO_{2eq}	
Production P_2O_5 fertilizer	G/kg P				714	[62]
Production urea	kg/kg N				1.3	[51]
Ammonium phosphate	kg/kg N				2.8	[59]
Tuck, lorry 28 t	G/tkm				223	[59]
Train, freight, rail	G/tkm				37.2	[59]
Diesel truck/machinery	G/liter				3644	[62]
Ship transoceanic tanker	G/tkm				5.52	[59]
Ship barge tanker, inland ship	G/tkm				42.4	[59]
Electricity medium volt. ARG	G/kWh				629	[59]
Natural gas, also for heating	G/MJ				62	[62]
Coal production and transport	g/MJe	20.9	0	0.34	28.0	[57]
Electricity production coal	g/MJe	247.5	2.4×10^{-3}	2.9×10^{-3}	2.5×10^{3}	[57]
Heat production natural gas[a]	G/MJ th				68.6	[60]
Conversion boiler	g/MJ th				2.5[b]	[57]
Seeds[c]	kg/kg				105	[59]
Metsulfuron[d]	kg/kg				8.8	[59]
Master/endosulfan[e]	kg/kg				5.8	[59]
Cipermetrina[f]	kg/kg				28.3	[59]
Roundup – glysophate[g]	kg/kg				15	[59]
Curasemilla (fungicide)[h]	kg/kg				5408	[62]
Hexane, at plant	kg/kg				0.9	[59]
Phosphoric acid, 85% H_2O	kg/kg				1.4	[59]
Tap water, at user	kg/kg				3×10^{-4}	[59]
Methanol at plant	kg/kg				0.7	[59]
Hydrochloric acid, at plant	kg/kg				0.8	[59]
EF wheat animal feed	kg/ton				744	[58]
EF synthetic glycerine	kg/kg				9.6	[61]
EF fatty acids vegetable oil[i]	kg/kg				1.2	[60]

[a] Based on Heat, natural gas, at boiler modulating >100 kW, European situation.
[b] Based on GEMIS wood pelleting D 100% conversion.
[c] [59] uses pea seed (regional storage) from Ecoinvent database as reference for soybean seed.
[d] Metsulfuron based on sulfonyl-urea compounds (at regional warehouse).
[e] Endosulfan based on Master (commercial name).
[f] Cipermetrina (commercial name Lorsban Plus) based on pyretroid and organophosphorus compounds.
[g] Input data Roundup given in liter, converted based on density of 1.17 kg/l for classical formula Roundup [63].
[h] EF curasemilla based on the general EF for herbicides from [62] due to lack of more specific data.
[i] Fatty acids, from vegetarian oil, at plant European.

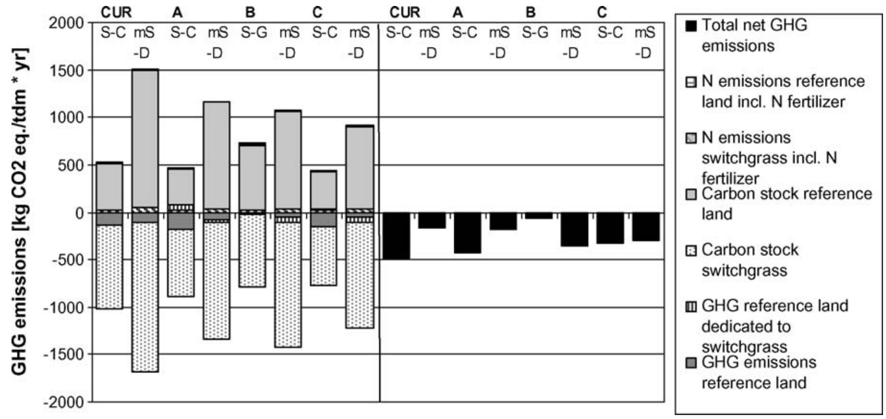


Fig. 5. Total GHG emissions of biomass and reference land-use system (left) and net GHG emissions from switchgrass cultivation for bioenergy (right) estimated over 20-year period in kg CO_{2eq}/tdm/year for current situation and for scenarios A, B and C to 2030.

The total GHG emissions from the reference land use system are GHG emissions coming from the use of inputs as fertilizers, seeds, diesel input and herbicides use. The amount of inputs for the reference land use 'cropland' is the same as the amount of inputs calculated for soybean production for bioenergy for a defined scenario. The amount of inputs needed for the reference land uses non-degraded and degraded grassland is the same as the amount of inputs calculated for switchgrass production. For degraded grassland, no fertilizer input is assumed, though.

Leakage due to biomass production is excluded in this study (see Section 4.1). The intensification of the reference land use system in the various scenarios (according to the storylines) compared to the current situation results in a change in the amount of inputs needed for cultivation. This change in amount of inputs, and consequently in GHG emissions, of the reference land use over time is allocated to the biomass system.

Bioenergy chains that involve the provision of more than one product or service require that the GHG emissions from inputs and outputs need to be subdivided between them, which is possible by a substitution approach or by allocation based on price, mass or energy content [55]. The switchgrass bioenergy chain does not have by-products in its chain. The soybean bioenergy chain has three by-products: pellets, glycerine and free fatty acids. There is an ongoing discussion which allocation or substitution method should be preferred or whether this decision should be upon the user. The draft Renewable Energy Directive from the European Commission proposes that allocation is based on energy content [49]. This approach has been adopted by various national governments [32,33,56]. Therefore, in this study, GHG emissions in the soybean bioenergy chain are allocated to the product based on energy content. Alternative scenarios (see Section 4.2.2) show the sensitivity results if other allocation options are used. The input data used for the GHG calculation of the two-bioenergy chains are shown in Table 4 [51,57–63].

4.2.1. GHG balance of the switchgrass bioenergy chain

The GHG emissions from fuel use, K and P fertilizer input, seeding and herbicides input for switchgrass cultivation range from 15 (B-S-G) to 54 (CUR-mS-D) kg CO_{2eq}/tdm/year. The main source of the GHG emissions is fossil fuel use, followed by P fertilizer input. In comparison, GHG emissions in an European situation are estimated to be 104–127 kg CO_{2eq}/tdm in 2004 to 103–123 kg CO_{2eq}/tdm in 2030 for switchgrass production, storage, un-loading and transportation (100 km distance) with the latter three items representing together around 20 kg CO_{2eq}/tdm [62].

Fig. 5 (left side) shows the total GHG emissions for switchgrass cultivation and its reference land use system including carbon stocks, indirect and direct N_2O emissions and extra emissions of the reference land use system due to intensified use of the land dedicated to bioenergy production. Total GHG emissions are largely determined by the carbon stock changes (see also Section 4.1). The inputs from switchgrass cultivation represent only a small part of it. The net GHG emission results for switchgrass cultivation range from −93 (B-S-G) to −484 (CUR-S-C) kg CO_{2eq}/tdm/year.

The GHG emissions for electricity production in the Netherlands from switchgrass pellets produced in Argentina transported by truck, range from −140 (CUR-S-C) to 76 (B-S-G) g CO_{2eq}/kWh$_{el}$ (Fig. 6). GHG emissions decrease slightly when train transport is used for this route from −172 (CUR-S-C) to 49 (B-S-G) g CO_{2eq}/kWh$_{el}$. The total GHG emissions for heating in Argentina from

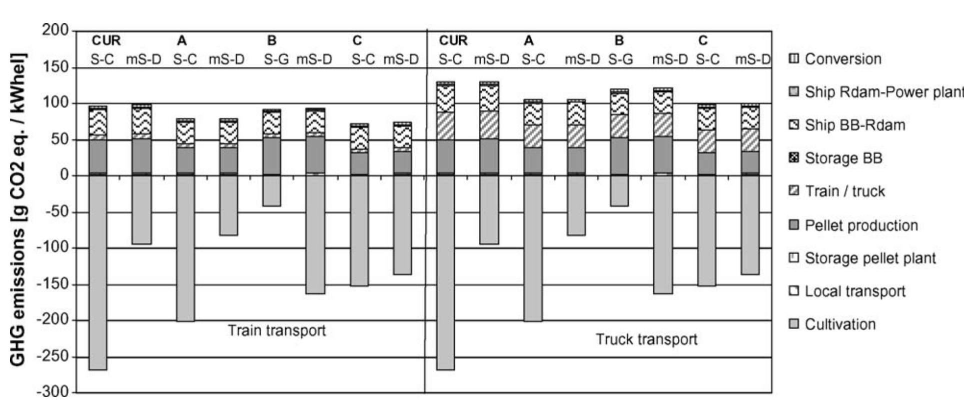


Fig. 6. Total GHG emissions for switchgrass bioenergy production for electricity generation replacing coal in g CO_2 eq/kWh$_{el}$. The biomass is exported from Argentina to the Netherlands by truck or train (inland). Outcomes for the current situation and for scenarios A, B and C for year 2030 are presented.

Table 5
GHG reduction (in %) for current situation and for scenarios A, B and C shown for switchgrass bioenergy production used for electricity generation in the Netherlands, replacing coal use, or for local heating in Argentina, replacing natural gas use. Inland transport is by truck or train. The results are differentiated to three lifetime periods.

Scenarios	CUR		A		B		C		REF[a] in g CO_{2eq}/GJ th-el
	S-C	mS-D	S-C	mS-D	S-G	mS-D	S-C	mS-D	
Export-train									
20 years	117%	100%	112%	100%	95%	107%	108%	106%	993.5 (in GJel)
50 years	103%	94%	102%	96%	95%	97%	101%	100%	993.5 (in GJel)
100 years	99%	93%	99%	95%	92%	96%	99%	98%	993.5 (in GJel)
Export-truck									
20 years	114%	96%	110%	98%	92%	104%	106%	104%	993.5 (in GJel)
50 years	100%	91%	99%	94%	90%	95%	99%	97%	993.5 (in GJel)
100 years	96%	90%	96%	93%	89%	93%	97%	95%	993.5 (in GJel)
Local use									
20 years	133%	103%	128%	104%	94%	117%	120%	116%	246.9 (in GJth)
50 years	109%	94%	107%	96%	89%	100%	106%	103%	246.9 (in GJth)
100 years	102%	92%	102%	94%	88%	95%	102%	99%	246.9 (in GJth)

[a] REF: emission factor reference energy system.

switchgrass pellets range from −82 (CUR-S-C) to 16 (B-S-G) g CO_{2eq}/kWh_{th}. The contribution of the different process steps to total GHG emissions for the various scenarios (see Fig. 7) is 27–74% for the cultivation process, 12–37% for the pelleting process and 12–40% for transport.

Table 5 shows the GHG reduction potential (in %) for switchgrass bioenergy production for electricity generation in the Netherlands (replacing coal) or for local heating (replacing natural gas). The GHG reduction of the switchgrass bioenergy chains (local use and export) ranges from 88% to 133% for varying lifetime periods (see also Section 4.1). The high GHG benefits on the short-term of 95–117% reduce somewhat to 92–99% on the long-term.

Based on the results, a conclusion is given about the relative performance of the switchgrass bioenergy chain for this principle. The highest score (++), with a GHG reduction potential of at least 85% for a lifetime period of 20 years, is achieved for all scenarios.

As mentioned, there is a large insecurity range in the calculation of the GHG emissions, based on IPCC [31]. Hilbert and Muzio [64] indicate for example a variation of 15% in the calculation of the GHG balance in Argentina which means a range of 30–60% for a calculated GHG reduction performance of 45%. Although a final comparison between the scenarios can therefore not be made, some indications can be given.

Generally, the highest GHG reduction performance is estimated when switchgrass production replaces abandoned cropland (CUR-S-C, A-S-C, and C-S-C). Replacing non-degraded grassland (B-S-G), results in a relatively low GHG reduction potential.

In absolute terms, most GHG emission is estimated when switchgrass pellets are exported to the Netherlands to replace coal. Also, from an economic perspective, the use of switchgrass pellets for energy conversion in the Netherlands is more attractive than for local use on the short-term [6].

4.2.2. GHG balance of the soybean bioenergy chain

The GHG emissions coming from fuel use, K and P fertilizer input, seeding and herbicides input for soybean cultivation range from 133 (CUR-S-C) to 250 (B-mS-D) kg CO_{2eq}/tdm/year. The higher emissions in kg CO_{2eq}/tdm for scenario (B-mS-D) can largely be dedicated to the low yields assumed for this scenario [6]. Fig. 7 (left side) shows the total GHG emissions for soybean cultivation (whole crop) and the reference land use system including carbon stocks, indirect and direct N_2O emissions and extra emissions of the reference land use system due to intensification of land use that can be dedicated to the bioenergy system. The net GHG emission results for soybean cultivation are largely determined by carbon stock changes (see also Section 4.1).

Soybean is a biological nitrogen fixation (BNF) crop. The soybean crop can affect N_2O emissions by taking up water and NO from the soil, thus reducing N_2O emissions [65]. Crops with a low C/N ratio like soybean display on the other hand high decomposition rates, releasing soluble C and N, thus increasing N_2O emissions [65,66]. The total direct N_2O emissions in Argentina from 1990/1991 to 2000/2001 increased sharply by 85%. Lamers [47] explains this increase by the percentual increase of BNF crops (with a strong increase in soybean production after 1996/1997) compared to legume crops and forages as well as by the burying of agricultural residues.

Soybean can be produced without or with nearly zero nitrogen, which is assumed for the current situation. Due to the expected imbalance of nutrients over time (see also Section 4.5), an increased use of phosphate monoamonico (12% N, 52% P) is assumed for the future scenarios, see also [6]. The increase in N fertilizer combined with N emissions from mineralisation of soil organic matter (see Section 4.1), results in an increase in the nitrogen emissions in some of the scenarios, especially in those replacing degraded grassland.

Mind that the Tier 1 methodology from IPCC [31] is based on general input data for N emissions from soybean cultivation. Large insecurities in results are discussed by various authors [53,67]. Some first measurements in Mendoza, Argentina, indicate a N-content of below-ground residues of 0.74 kg N/kg DM [68] compared to an IPCC-value of 0.008 kg N/kg DM. More accurate input data are needed on N_2O emissions and also on management practices, as the latter can reduce GHG emissions (lower energy input) and carbon stock changes.

The net GHG emission results (see Fig. 7, right side) results for soybean cultivation (whole crop) show a large variation ranging from 0.0 kg CO_{2eq}/tdm year (CUR-S-C) to 4294 kg CO_{2eq}/tdm year (B-mS-D). The GHG emissions from inputs for cultivation, as fuel or fertilizer use, are limited. The land use reference system, and the resulting carbon stock changes, is the main determinant for the net GHG emissions for soybean cultivation.

The energy efficiency of the vehicles for fossil fuels and a blend of fossil fuels—biofuel are assumed to be the same, being 183.1 MJ/100 km in an European situation for both diesel and diesel mixed with 5% biodiesel according to JRC [69]. The GHG emissions for the bioenergy production chain from soybeans are therefore calculated until delivery of the fuel at the pump.

Fig. 8 shows the total GHG emission for biodiesel production for export to the Netherlands for the current situation and for

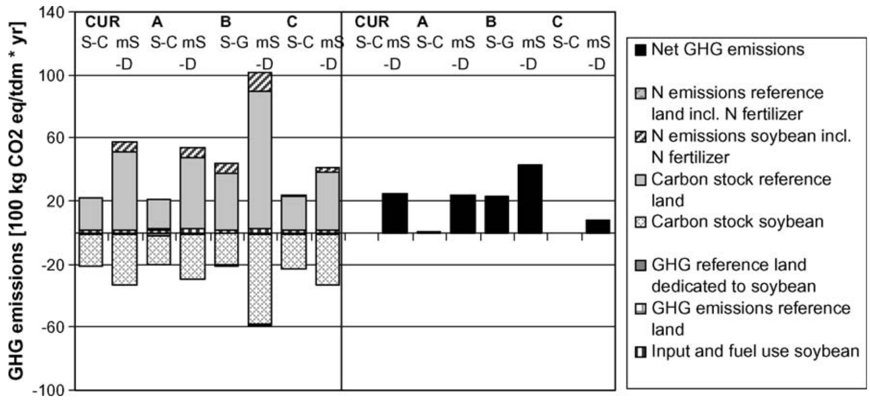


Fig. 7. Total GHG emissions from soybean and reference land-use system (left) and net GHG emissions of soybean cultivation (whole crop) for bioenergy (right) estimated over 20-year period in 100 kg CO_{2eq}/tdm/year for current situation and for scenarios A, B and C to 2030.

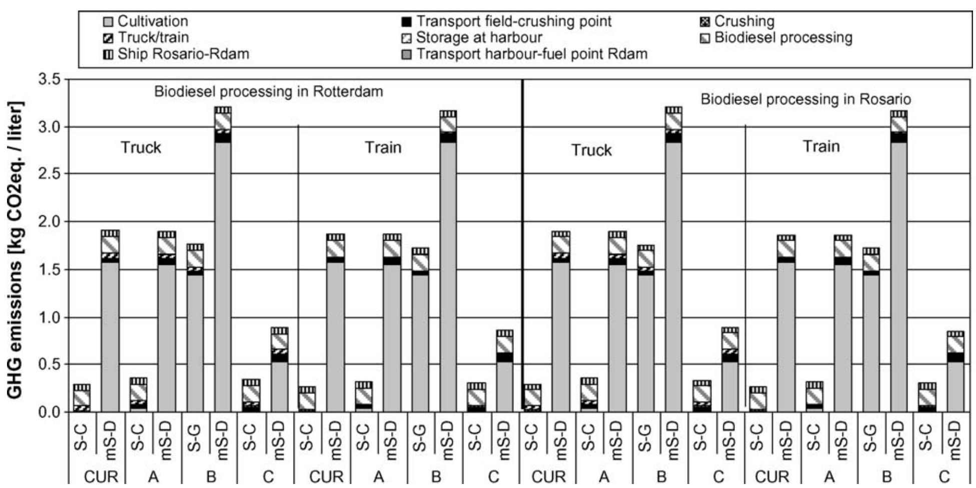


Fig. 8. Total GHG emissions for soybean biodiesel production (produced in Rotterdam in the Netherlands or in Rosario in Argentina) in kg CO_{2eq}/l for export from Argentina to the Netherlands with truck or train (inland), for current situation and for scenarios A, B and C in year 2030.

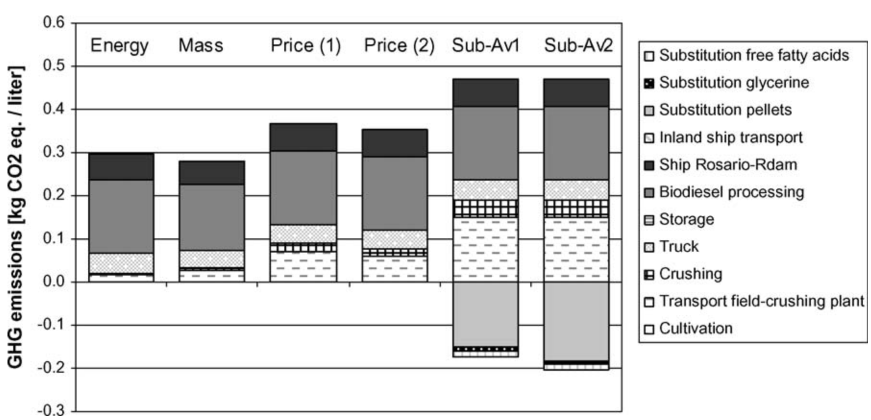


Fig. 9. GHG emission results in CUR-S-C in kg CO_{2eq}/l for varying possibilities of allocation choices and substitution (Price (1): based on pellet price 385 US$/ton, glycerine price 50 US$/ton, soy oil price 1390 US$/ton, biodiesel price ARG 583 US$/ton, Price (2): based on on pellet price 214 US$/ton, glycerine price 0 US$/ton, soy oil price 615 US$/ton, biodiesel price ARG 583 US$/ton, Sub-av (1): pellets and glycerine biodiesel chain are replaced with soybean pellets feed/food chain, GE soybeans = 5.5, $EF_{average}$ = 67.2 kg CO_{2eq}/ton product. Sub-av (2): pellets and glycerine biodiesel chain are replaced with maize for animal feed, GE maize = 4.4; $EF_{average}$ = 64.6 kg CO_{2eq}/ton product) for biodiesel processing in Rosario with truck transport.

scenarios A, B and C. The results range from 0.3 kg CO_{2eq}/l (CUR-S-C-train-ROS)[7] to 3.1 kg CO_{2eq}/l (B-mS-D-truck-ROT)[7] which is 0.3 and 3.5 kg CO_{2eq}/kg biodiesel, respectively. In comparison, Panichelli [59] calculated a GHG emission for biodiesel transported to Switzerland (delivered at pump) of 1.7, 1.4 and 4.0 kg CO_{2eq}/kg biodiesel when produced in Argentina, USA and Brasil respectively. The GHG emission results for biodiesel (see Fig. 8) are largely determined by the impacts of land use change (see Section 4.1). Transport and biodiesel processing contribute respectively 33% and 66% to the total calculated GHG emissions for the scenario (CUR-S-C-train-ROS). GHG emissions from biodiesel production for

[7] The soybean bioenergy chain distinguishes between biodiesel conversion in Rosario (ROS) and in Rotterdam (ROT). Inland transport is by means of truck or train.

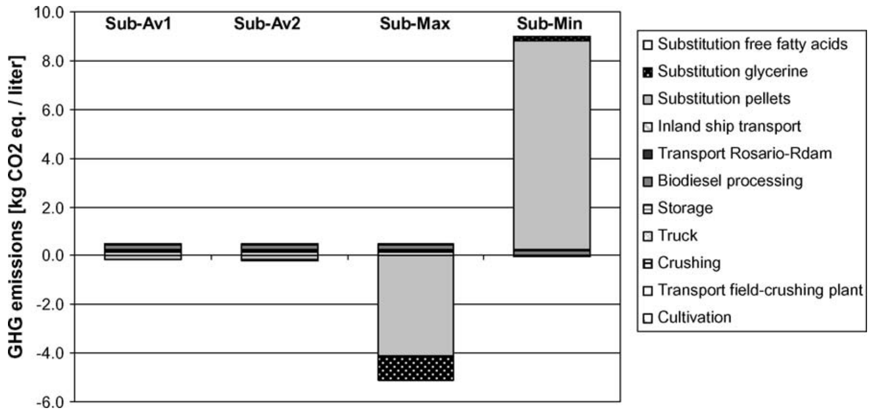


Fig. 10. GHG emission results in scenario CUR-S-C in kg CO_{2eq}/l for different substitution choices (Sub-min and Sub-max reflect maximum and minimum EF found in literature. Sub-min: Soybean pellets are replaced by animal feed coming from extensive hay production. GE = 4.5, EF = −1553.3 kg CO_{2eq}/ton product. Sub-max: Soybean pellets are replaced by wheat bran, GE = 4.5, EF = 744 g CO_{2eq}/ton product. Glycerine in the biodiesel process is replaced by synthetic glycerine. GE = 4.3; EF = 9600 kg CO_{2eq}/ton product), based on various literature sources, for biodiesel processing in Rosario with inland truck transport from the crushing to the biodiesel plant.

local use range from 0.2 kg CO_{2eq}/l (CUR-S-C-train-ROS) to 3.0 kg CO_{2eq}/l (B-mS-D-truck-ROS). GHG emissions are lower when the train is used for inland transport combined with biodiesel processing in Rosario.

Figs. 9 and 10 show the range in GHG emission results for scenario (CUR-S-C-truck-ROS) when different allocation methods (mass, price and energy) and substitution options are used. Variations in price data are based on [6,70]. Variation in the input data for substitution is based on data ranges of the replaced by-product derived from various literature sources [51,60,61,71,72]. The gross energy values (GE) for animal feed are based on [73]. The estimated range in results when different allocation methods are used is 0.3 to 0.4 kg CO_{2eq}/l, which leads to a variation in GHG reduction performance ranging from 90% to 92%. The estimated range in results when different input data (between minimum and maximum values found in literature) for substitution are used is −4.7 to 9.0 kg CO_{2eq}/l, which leads to a variation in GHG reduction performance ranging from −147% to 228%. The estimated range in results between options (Sub-av1) and (Sub-av2) is 0.02 kg CO_{2eq}/l. The results show that price allocation is quite sensitive to price fluctuations while results in substitution can vary according to the product replaced and the data sources used for that product. This creates a large uncertainty in the results. Allocation of GHG emissions based on energy content is therefore preferred.

Table 6 shows the GHG reductions (in %), based on allocation of energy, for the various scenarios for biodiesel production from soybean, ranging from 16% to 94% for varying lifetime periods (20–100 years). In comparison, Hilbert and Muzio [64] have calculated the GHG balance for biodiesel from intensive soybean cultivation in Santa Fe province resulting in a GHG reduction of 74% (with a

Table 6
GHG reduction (in %) for current situation and for scenarios A, B, and C for soybean bioenergy production, replacing fossil diesel use. Soybean is produced in La Pampa. Biodiesel processing is located in Rosario or in Rotterdam. The biodiesel is exported or locally used. The results are presented for three lifetime periods.

Scenarios	CUR		A-2030		B-2030		C-2030		REF[a] diesel in kg CO_{2eq}/l
	S-CR	mS-D	S-CR	mS-D	S-GR	mS-D	S-CR	mS-D	
Export chain-inland transport by train – biodiesel processing in Rosario									
20 years	93%	49%	91%	50%	53%	16%	92%	77%	3.64
50 years	93%	75%	91%	74%	80%	62%	92%	85%	3.64
100 years	93%	83%	91%	82%	86%	75%	92%	87%	3.64
Export chain-inland transport by truck – biodiesel processing in Rosario									
20 years	92%	48%	90%	49%	52%	15%	91%	76%	3.64
50 years	92%	74%	90%	73%	79%	61%	91%	84%	3.64
100 years	92%	82%	90%	81%	85%	74%	91%	86%	3.64
Export chain-inland transport by train – biodiesel processing in Rotterdam									
20 years	93%	49%	91%	50%	53%	16%	92%	77%	3.64
50 years	93%	75%	91%	74%	80%	62%	92%	85%	3.64
100 years	93%	83%	91%	82%	86%	75%	92%	87%	3.64
Export chain-inland transport by truck – biodiesel processing in Rotterdam									
20 years	92%	48%	90%	49%	52%	15%	91%	75%	3.64
50 years	92%	74%	90%	73%	79%	61%	91%	84%	3.64
100 years	92%	82%	90%	81%	85%	74%	91%	86%	3.64
Local use of biodiesel – inland transport by train – biodiesel processing in Rosario									
20 years	94%	51%	93%	52%	55%	18%	93%	78%	3.64
50 years	94%	77%	93%	76%	81%	64%	93%	87%	3.64
100 years	94%	85%	93%	83%	88%	77%	93%	89%	3.64
Local use of biodiesel – inland transport by truck – biodiesel processing in Rosario									
20 years	93%	50%	92%	51%	53%	17%	92%	77%	3.64
50 years	93%	76%	92%	75%	80%	63%	92%	86%	3.64
100 years	93%	84%	92%	82%	87%	76%	92%	88%	3.64

[a] REF: emission factor reference energy system.

variation of 15%). This is in line with the results of this study. Typical values for biodiesel from soybean estimated by JRC [74] are between 31% and 40%.

Based on the results, a conclusion is given about the relative performance of the soybean bioenergy chain for this principle. The scenarios replacing abandoned cropland (CUR-S-C, A-S-C, and C-S-C) have the highest score (++). A relative high score (+), with a GHG reduction requirement of more than 35% [49], is estimated for the scenarios replacing degraded grassland and for scenario (B-S-G). Scenario (B-mS-D) does not meet the GHG reduction requirement of 35%, based on a lifetime period of 20 years. Mind that the GHG reduction performance improves for the soybean bioenergy chain when longer lifetime periods are assumed. As Table 6 shows, scenario (B-mS-D) would meet the GHG reduction requirement of 35% when a lifetime period of 50 years or more is assumed.

4.3. Principle 3: biomass production must not endanger food supply and local applications

Principle 3 deals with land competition and the use of land for the production of energy carriers in state of food, feed or other applications. No defined methodology is yet established to map out the effects of the production of biomass for energy carriers on food security and other local applications and to evaluate these effects related to sustainability standards. Cramer et al. [30] recommend that most aspects of this theme are monitored at a macro level. For doing this, the following data on project level are needed: food prices, land prices, ownership of land and availability of food. In this study, we will use the reporting approach and parameters mentioned by Cramer et al. [30]. Also, we start from the assumption that in the reference case food and feed production meets the demand [6]. The following criteria are used:

I. Economic effects of land use for bioenergy production with as indicators: impacts on land and food and feed prices;
II. Land use change due to biomass production with as indicators: expected changes in land ownership, in vegetation and in crop pattern.

At present, no standardized methodology exists yet to assess these indicators. This study looks at ongoing price and land use trends in the defined region to place the information in a macro perspective and to estimate impacts of bioenergy production following the selected indicators.

4.3.1. Economic effects of land-use for bioenergy production: land prices

Land prices increased strongly in the last few years in Argentina. Average increases of 10% in agricultural land rents in 2006/2007 compared to the previous year are mentioned by Bertello [75]. Similar increases (10–15%) are mentioned for 2007/2008 [76]. This is caused by various factors [75]. Land rents are pushed by high outputs and price levels for annual crops as soybean or maize. This creates good income perspectives for farmers, especially with the expectation of further increasing yields. Consequently, there is a high demand for renting suitable land for annual crop production and a supply that does not catch up. Also, the agricultural sector is seen as a secure financial investment. The increase in land rents as well as other costs and investment costs forces producers to select a crop with sufficient income [75].

The land rental costs (see Table 1) have been determined for the various scenarios, based on assumptions on demand and price of the harvested product and the availability of land for biomass production [6].

Some first conclusions on the relative performance of the bioenergy chains for this criteron can be drawn but should be taken with caution. A negative score, with an increase in land price of 20% or more compared to the current situation, is estimated for scenarios A and C in the soybean bioenergy chain and for scenario (A-S-C) in the switchgrass bioenergy chain. A positive score, with a decrease in land price compared to the current situation, is estimated for scenarios (B-S-G) and (C-S-C) in the switchgrass bioenergy chain, due to a larger availability of surplus land from perennial fodder [6].

4.3.2. Economic effects of land-use for bioenergy production: food and feed prices

Due to high inflation rates, food prices in Argentina have increased in the last few years although the government announces yearly a maximum price to avoid strong increases for the principal food products. The price of products falling in the category "oils and fats" increased strongly between 2002 and 2007 due to a strong international demand and insufficient production [77]. As the price increased 218% in the period 2002–2006, the government agreed to provide a subsidy to keep local price increases within a bandwidth. This agreement was ratified in June 2007. Related to this development, Marelli and Pristupluk [77] mentions a shortage of vegetable oils (especially sunflower oil followed by other oil types), caused by limited production capacity and increasing (international) demand.

The demand on products from biomass for energy production increases as well over time, depending on the scenario, which is reflected in the price of these products. Assumptions about the price of switchgrass (pellets) and soybeans (meal, vegetable oil) are included in the various scenarios [6]. These prices are expected to increase over time with the highest price increase for scenario C. At present, these products are largely produced for export and not for internal demand. For example, more than 90% of the soybean meal is exported [48]. An increase in biodiesel production (around 20% of the harvested soybean production), will result in a stronger increase of valuable protein (around 80% of the harvested soybean production). This may result in a surplus of flour [48] and consequently in a price decrease. The intensification of livestock in Argentina over time in the various scenarios in this study provides a growing market for this product, though. The required production from feed crops increases, for example, from 8×10^3 tons in the current situation to 35×10^3 tons in scenario C in 2030 [6].

The dynamics of food and feed prices over time is influenced by a wide range of factors (demand for land, development of international markets, growth of economies, labour costs, etc.) partly embedded in the storylines of the scenarios. A clear conclusion on the effect of a biomass energy production project in the region on food and feed prices can therefore not be drawn as this is beyond the limits of this study. A first indication can be given, though. Food and feed prices, as assumed in the scenarios, will increase. This increase goes hand in hand with economic growth [6]. Whether this increase shows a linear or non-linear relation with the expected economic growth cannot be said.

4.3.3. Land use change due to biomass production

Human induced land use changes are already happening in La Pampa province since the 1800s. Until 1980, the area of cropland and cultivated pasture has expanded displacing cattle production to the semi-arid, marginal lands of the western pampas [78]. The conversion of natural grasslands into cultivated grasslands was not homogenous. No single crop has expanded all over the region and livestock has not been removed from better lands in all areas. The process of overgrazing in the semi-arid region of La Pampa already

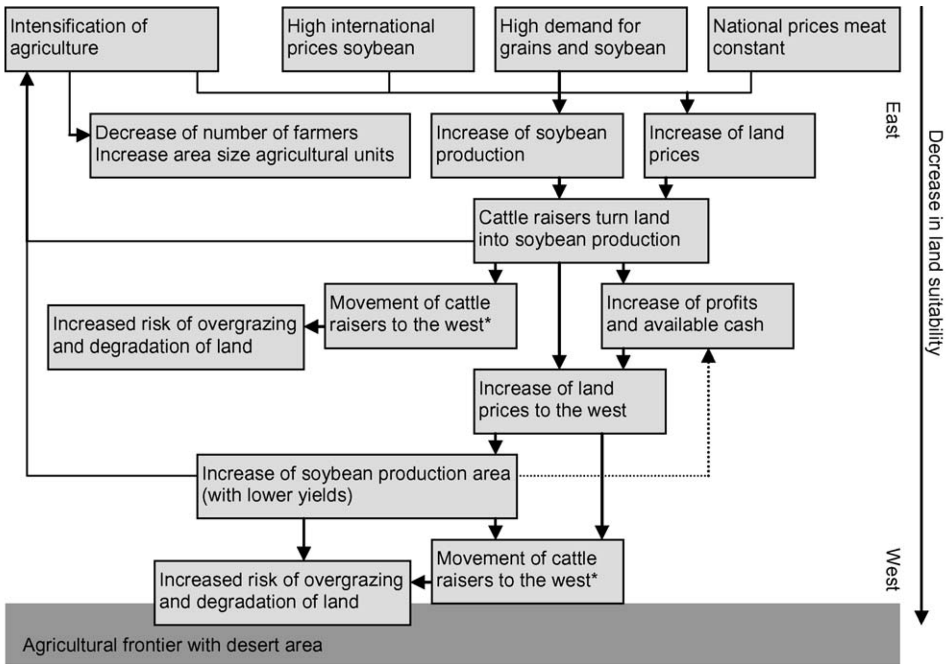


Fig. 11. Schematic picture of the current land use changes in La Pampa province. *Cattle raisers, moving to the west, in generally do not adapt their cattle load (number of livestock/ha) to the less productive areas.

started in the beginning of the 1900s [79]. Recently, a high profitability of annual crops, combined with an increase in precipitation and increased use of no-tillage management [80], has enlarged the area under agricultural rotation, which in return leads to increasing pressure on the west frontier of the semi-arid region of La Pampa province. The associated displacement of cattle generates a significant increase of the cattle load to the west, to areas dominated by natural pasture. This trend (Fig. 11) has already caused the loss and degradation of natural grasslands and severe erosion processes [24]. The recent land use changes in La Pampa province are mainly caused by economic incentives for the farmer, receiving high prices for annual crops, and the possibility to extend the production of profitable crops to other areas within the region. Livestock production is traditionally characterized by low productivity, income and profit. The need for large areas and the low profit per area makes livestock production only viable in areas where land prices are low. Consequently, when infrastructure improves and more intensive land uses as soybean production start to predominate, cattle production will be displaced, intensified or decreased. Displacement can lead to ecosystem degradation, as shown in Brazil [81].

In this study, it is assumed that leakage, as the displacement of extensive cattle production due to biomass energy production, can and will be avoided (see Section 4.1). Direct land use changes that still can be expected in La Pampa province in the various scenarios are shown in Fig. 12. The contribution of bioenergy production to these land use changes is, however, difficult to define. A clear conclusion on the impact of biomass energy production on land use changes can therefore not be drawn, although some first indications can be given:

- Although leakage is not an issue in this study, it is an existing problem in the selected region. Therefore, care must be taken to further provoke the ongoing conversion of pasture areas, including natural habitats, to cropland areas. Bioenergy production on non-degraded grassland areas (B-S-G) may therefore be an undesirable action as it can cause important leakage effects;

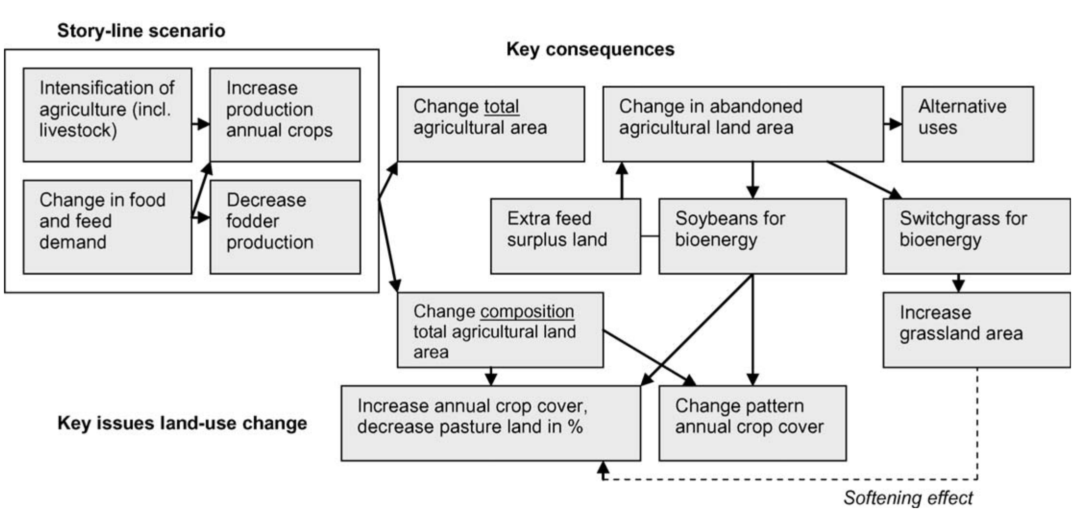


Fig. 12. Key consequences and expected direct land-use changes in scenarios according to story lines.

- Soybean production for bioenergy will strengthen the already ongoing conversion of grassland areas to cropland areas and will contribute to an ongoing change in land ownership in the region. This impact is expected to be limited when soybean for bioenergy is produced on abandoned cropland areas (CUR-S-C, C-S-C and A-S-C). Switchgrass production is expected to soften the ongoing land use changes;
- When pellets produced in the soybean bioenergy chain are used within the region for livestock production, surplus land will be generated [6]. As only a limited amount of this land meets the individual crop requirements for soybean production [6], the remaining land may come available for alternative options (grassland, nature protection, switchgrass production), which will have a softening effect on the ongoing land use changes in the region.
- The competition between the use of land for biomass energy production or for other annual crops is smaller for switchgrass than for soybeans as the agroecological area (taking into account the individual crop requirements) for switchgrass production is larger [6].

Thus, switchgrass production may have a relative positive performance for this criterion, due to its softening impact on ongoing land use changes, while soybean production may have a relatively negative performance.

4.4. Principle 4: biomass production must not affect biodiversity

Cramer et al. and the European Commission [30,49] propose that biomass plantations must not be located in protected areas or areas with a high conservation value. This neglects the effects from biomass energy production on biodiversity outside HCV areas. Dornburg et al. [82] recommend therefore to include this aspect in a biodiversity impact analysis. The impact of biomass production on *total* biodiversity is estimated in this study by investigating:

I. The probability of biomass production in HCV areas;
II. the impact of biomass production on local biodiversity (agro-biodiversity).

Forest areas and protected areas (see Map 1) are excluded from biomass production [6] in this study. Consequently, the reduction of HCV areas due to biomass production should not happen. Therefore, this aspect will not further be discussed. The possible impact of large-scale biomass production on the agro-biodiversity in the region [82], due to changes in the biodiversity value as a result of land converted to bioenergy crop production, is estimated by the 'Mean Species Abundance' (MSA). The MSA is used by Dornburg et al. [83] as an indicator for the short-term impact on the biodiversity on land converted from actual land uses to bioenergy crop production. The possible impact of (increased) herbicides and pesticides use from biomass energy production on the local biodiversity in the region, as mentioned by Berkum et al. [84], is included in the MSA value. Available literature is used as an additional verifier for the MSA indicator.

Although a stakeholder consultation to designate biodiversity values in the region, as applied in the HCV methodology [85], would have been valuable for this study, this was not possible due to time limitations. The compliance of national and local regulations, as suggested by Cramer et al. [30], is not further discussed as the protection of biodiversity is incorporated into national and provincial regulations (see Section 3.1).

4.4.1. Possible impacts of bioenergy cultivation on the agro-biodiversity in La Pampa province

It can be concluded from Sections 3.1 and 4.3 that the natural pasture land areas, including the 'Bosque de Caldén' should be protected to maintain its biodiversity. Important for the local biodiversity of biomass energy production areas are the crop type and the reference land use system [82]. Whether a given biomass production system can contribute to biodiversity depends also on the prevailing local species and the type of habitats they require. Crop types should be favored that match native ecosystem types [86].

Table 7 shows the MSA values and the expected impacts of biomass production from soybeans and switchgrass on the biodiversity values in La Pampa province [40,62,83,87]. As no MSA value is available for biomass production replacing extensive grasslands in the temperate zone [82], the value for extensive grasslands in the tropical zone is used instead for scenario (B-S-G).

Based on the results, a conclusion is given about the relative performance of the bioenergy chains for this principle. Relatively high scores, meaning the MSA indicator is positive, are estimated for the scenarios replacing abandoned cropland with switchgrass production (CUR-S-C, A-S-C, and C-S-C), especially when cropland with a conventional management system (A-S-C) is replaced. Although switchgrass production on degraded grasslands has a

Table 7
Expected impacts and MSA values for biomass production from soybeans and switchgrass replacing various land-use systems. A negative MSA value indicates a biodiversity decrease; a positive value indicates a biodiversity increase.

Reference land-use	MSA	Bioenergy system	Expected impacts
Existing grassland (intensive, in temperate region)	0	Soybean	Change in original natural ecosystem (pasture, Caldenal region) and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors [87]
	+0.2	Switchgrass	Positive impacts on biodiversity [62] due to increase in soil micro-organisms, soil fauna and niches for various species [40]
Degraded grassland (marginal land)	−0.2	Soybean	Change in original natural ecosystem (pasture, Caldenal region) and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors [87]
	0	Switchgrass	Possibilities to restore biodiversity if sustainably managed.
Existing cropland (intensive, in temperate region)	0	Soybean	No disruption of ecosystems
	+0.2	Switchgrass	Positive impacts on biodiversity [62] due to increase in soil micro-organisms, soil fauna and niches for various species [40]
Extensive grassland (tropical region)	−0.2	Soybean	Change in original natural ecosystem (pasture, Caldenal region) and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors [87]
	−0.1	Switchgrass	Match to existing original ecosystem types (pasture, Caldenal region) in La Pampa province (limited disruption)
Natural vegetation	−0.4[a]	Soybean	Change in original natural vegetation and its forms of life which leads to disruption of ecosystem. Risk for possibility of defragmentation of corridors [87]

[a] The conversion of existing cropland to natural vegetation has a MSA value of +0.4.

neutral score, possibilities to restore biodiversity if sustainably managed may be possible. Negative scores, when the MSA indicator is negative, are estimated when biomass production replaces non-degraded grassland. Soybean production on non-degraded grassland also results in a negative score. This effect can be minimized when the feed produced (80% of whole crop) is used within the region for livestock production. For example: 65×10^5 ha of extra land (a 38% increase) with variable land suitabilities can be generated in scenario C in 2030 [6]. When we assume that with every hectare of abandoned cropland for soybean production, 0.4 ha of extra generated land is used for grass cultivation (MSA = +0.2) or for restoration of the natural vegetation (MSA = +0.4), the MSA value from scenario (C-S-C) could change from 0 to 0.1 ($100\% \times 0 + 38\% \times 0.2$) or 0.15, respectively.

4.5. Principle 5: biomass production and processing and soil quality

This principle includes three criteria including no violation of national laws and regulations, the appliance of best practices and safeguarding that residual products must not be at variance with other local functions for soil conservation [30]. Cramer et al. [30] propose, beside compliance with legislation and best practices, reporting on (i) soil loss; (ii) N, P and K nutrient balance and (iii) soil organic matter and pH in the top layer of the soil. The compliance with legislation and best practices cannot be determined beforehand. The focus of this study is therefore on possible impacts of bioenergy production on soil loss, nutrient balance and soil organic matter (SOM). The soil loss is calculated using the so-called Universal Soil Loss Equation (USLE) as suggested by Smeets et al. [5]:

$$A = R \times K \times L_S \times C \times P \tag{3}$$

where: A is the soil loss (in ton/ha); R is the rainfall erosion index (in MJ mm/ha h); K is the soil erodibility factor (ton ha h/ha MJ mm); L_S is the length of slope factor (dimensionless); C is the crop/vegetation management factor (dimensionless); P is the agricultural practice factor (dimensionless).

The USLE equation calculates the water soil loss (in ton/ha year) under various vegetation types. Soil loss by wind erosion is not included in the equation. Input data used are shown in Table 8 [5,25,88–92].

The nutrient and SOM balance of the soil are determined by the inflows and outflows in the soil over a defined time period. Nutrient budget and nutrient-balance models exist on a regional and national [93,94] to farm level [95]. Applications of these methods [93–95] require a substantial amount of data, including field measurements for the collection of data on soil characteristics, material flows and crop nutrient requirements [96]. As this study looks beforehand at possible impacts from bioenergy production within a limited time frame, a more simplified approach is needed. The loss of nutrients from N, P and K is used as an indicator for the nutrient balance by Smeets et al. [97]. This approach requires data on the nutrient recovery efficient and on the mineral composition of the crops. The latter is affected by the composition of the soil, and thus by its location. A consistent data set for Argentinean circumstances for switchgrass and soybeans, required for this equation, is not available.

A reference indicator is therefore used in this study to analyze the SOM and nutrient balance of the soil, which is the net carbon stock change (as calculated in Section 4.1) as changes in soil carbon and soil organic matter (SOM) are highly interrelated [46,86]. La Pampa province is characterized by alkaline soils with pH values between 6 and 8.5 [98], which limits the risk for environmental acidity. Possible impacts of bioenergy production on the pH of the soil are therefore not further discussed in this study.

4.5.1. Soil erosion

The soil loss from soybean production varies from 2 (B-S-G) to 10 (A-mS-D, CUR-mS-D) ton/ha/year. The soil loss from switchgrass production is limited, ranging from 1 (CUR-S-C, A-S-C, B-S-C) to 2 (C-mS-D) ton/ha/year (see Fig. 13), as its permanent cover effectively controls surface water run-off. There is, however, an erosion risk for switchgrass production during its establishment phase as seedling growth rates of warm season grasses are often slow. This risk can be limited by using appropriate species and improved establishment systems that hasten attainment of the complete canopy cover [99].

Based on the results, a conclusion is given about the relative performance of the bioenergy chains for this criterion. The highest score (++), when the annual soil loss in the biomass production system is reduced with more than 2 ton/ha/year compared to the

Table 8
Input data and references for factors used in USLE equation.

Factors used in USLE	Input data		References
	S land	mS land	
Rainfall (mm/year)	700	600	[25]
R (in MJ mm/ha h)	1839	1435	Calculated
K (ton ha h/ha MJ mm)	0.03	0.04	[88]
Slope length (m)	61	61	[89]
Slope gradient (%)	4	5	[89]
LS (dimensionless)	0.58	0.76	Calculated
P (dimensionless)	0.5 for contour farming		[5]
C soybean (dimensionless)	• Soybean – conventional system : 0.45 Based on C data corn-soybean rotation for conventional tillage system (0.37–0.42) and for tillage system (0.25–0.48). • Soybean – no-tillage system: 0.15 Based on C data corn-soybean rotation, ranging from 0.1 to 0.28. Note: soybean residue provides less protective cover than corn silage • Soybean no tillage – high input: 0.30 Based on C data for continuous soybean (20% cover, average yield, conservative tillage) C = 0.31		[90-92]
C switchgrass (dimensionless)	• Intermediate agricultural input system: 0.05 • Mixed agricultural input system: 0.05 • High agricultural input system: 0.10		[5]
C degraded grassland (dimensionless)	0.40		Estimation
C grassland full coverage (dimensionless)	0.02 for hay and pasture in general		[89]

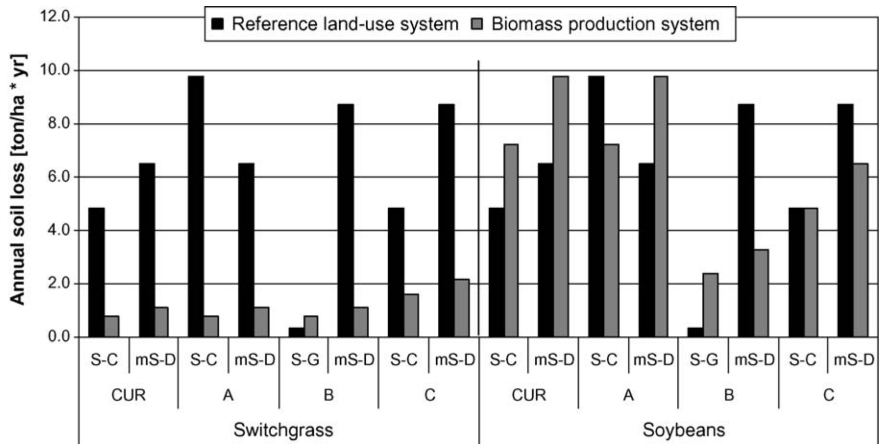


Fig. 13. Annual soil loss in ton/ha/year for switchgrass and soybean production for bioenergy for current situation and for scenarios A, B and C for the year 2030.

previous land use system, is found when soybean production with a no-tillage system (C-mS-D, B-mS-D) replaces degraded grassland. The use of no tillage or reduced tillage decreases soil erosion compared to repeated tillage [99] as there is a decrease in disruption of soil macro-aggregates and carbon turnover [100] and an improvement of the physical and hydrological properties of the soil [84]. The highest score is found when switchgrass replaces abandoned croplands (A-S-C, CUR-S-C) or degraded grasslands. A relatively high score (+), when annual soil loss in the biomass production system decreases with 0 to 2 ton/ha/year compared to the reference system, is found for scenario (C-S-C). These findings are confirmed by Kort et al. [99] mentioning an erosion reduction when cropland is converted to herbaceous biomass production in the US, especially in areas containing highly erodible land.

There are no changes in annual soil loss when soybean production replaces abandoned cropland (CUR-S-C, A-S-C and C-S-C). A negative score (−), when annual soil loss increases 0–2 ton/ha/year compared to the reference system, is found when soybean production replaces degraded grassland. Replacing non-degraded grassland with biomass production (B-S-G) creates an annual soil loss increase of 0.5 and 2 ton/ha/year for, respectively, switchgrass and soybean bioenergy production.

The results show the possible risks of bioenergy production for water soil erosion, excluding possible risks for wind soil erosion. The latter can be substantial in La Pampa province though, as [79] mentions that approximately 16×10^4 ha are moderately affected by wind erosion in plowed areas at the eastern part of La Pampa province while 185×10^3 ha have suffered severe damage.

4.5.2. Soil nutrient balance

Using carbon stock changes as an indicator (see Section 4.1); it can be assumed that most benefits in SOM can be achieved when switchgrass replaces cropland, followed by the replacement of degraded grassland. The results are confirmed by McLaughlin et al. [101] mentioning a significant increase in SOM after four years of switchgrass production in the US. The results from Section 4.1 indicate that a decrease in SOM can be expected when soybean production replaces degraded and non-degraded grassland.

According to the results from Section 4.1, there is no change in SOM content when soybean is produced on abandoned cropland. Various literature sources show, however, the risk for unbalance of nutrients when practising long-term intensive agriculture in Argentina. National research in 1999/2000 for vegetable oil and grain production estimated that only 50% of the consumed phoshor and 0.4% of the consumed potassium was brought back into the soil [102]. Similar results are shown by Galarza et al. [103]. Castino [104] mentioned that – in subsequent order – only 2%, 27% and 18% of the consumed nitrogen, phosphor and sulfur for soybean production was brought back into the soil. Explanations for these nutrient deficits are the high nutrient extraction from soybean (240 N, 27 P, 78 K kg/ha) compared to other annual crops and a further intensification of agriculture without sufficient inputs [104]. Soil nutrient deficits may result in a yield decrease [84,86]. The unbalance of nutrients for soybean for 2007/2008 in the region North Buenos Aires[8] was estimated to have an economic cost of 242 US$/ha [105].

Based on the results, an indication is given about the relative performance of the bioenergy chains for this criterion. A final conclusion cannot be given though, as the results show a large insecurity because the carbon stock change is used as a reference indicator. The ratings of the scores for different scenarios and systems are presented and explained in Section 4.1. Long-term intensive agriculture combined with no fertilizer use can result in nutrient deficits. For this reason, scenario (CUR-S-C) should have a more negative score for this criterion than indicated in Section 4.1.

4.6. Principle 6: biomass production and processing and water quality and quantity

Cramer et al. [30] state that ground and surface water must not be depleted and that the water quality must be maintained or improved during the production and processing of biomass. This principle has been translated to a set of criteria stating that biomass production and processing must not be at the expense of water from non-renewable sources, or at the expense of ground and surface water quality, and that national legislation and regulations must not be violated. Cramer et al. [30] propose to verify the risk for depletion of water sources by data on the use and origin of irrigation water and on water-use efficiency. As the use of irrigation for bioenergy production is excluded in this study [6], this will not be further discussed. Yet, the production of soybean and switchgrass may have an impact on the water balance in an area via changes in the evapotranspiration, runoff and percolation.

The possibility of water depletion due to biomass energy production is estimated by Smeets et al. [97] with a simple water balance equation in which the evapotranspiration is compared with the effective rainfall.

$$WS = -((ET_0 \times K_c) - P) \tag{4}$$

where: WS is the water shortage (mm/month); ET_0 is the reference evapotranspiration (mm/month); K_c is the crop evapotranspiration

[8] Based on the 1st planting and an average yield of 4 tdm/ha.

Table 9
Crop evapotranspiration coefficient K_c (dimensionless) and water-use efficiency (WUE) in product g DM/kg water transpired for selected crops.

Crop	K_c	Reference	WUE		Reference
			g DM/kg water	GJ/ton water	
Soybean	0.91	[108]	0.37–0.64	1.95–3.37[a]	[82]
			0.37–0.44		[112]
- Initial stage	0.5	[109]			
- Mid season	1.15	[109]			
- Late season	0.5	[109]			
Corn	1.0	[108]	0.7–1.41		[82]
			0.75–1.23		[112]
Wheat	0.87	[108]	0.69–0.86		[82]
Switchgrass	0.98	[110]			
Miscanthus			1–9.5	18.5–175.8[b]	[113]
			4.1–22		[82]
Pasture	0.98	[111]			
Pasture rotated grazing	0.95	[97]			
Energy crops			0.3–14.2		[114]
C3 crops			2–3		[115]
C4 crops			3.5–4.5		[115]

[a] Based on 18% oil content, 0.93 kg oil/l oil, 0.96 l biodiesel/l oil calculated per t DM.
[b] Calculated per t DM, energy content of 18.5 GJ/ton.

coefficient (dimensionless); P is the effective precipitation (mm/month).

The same formula is used in this study to estimate the possibility for depletion of water resources. Monthly precipitation data are available from the weather station Anguil in 2006/2007 [25]. Temperature data, required as input to calculate ET_0, are taken from a standardized data set for Santa Rosa (La Pampa) from the CROPWAT software tool [106]. The effective precipitation P and the reference evapotranspiration[9] ET_0 are calculated using CROPWAT [106]. The factor K_c[10] is the ratio between the actual non-water limited water demand to the reference evapotranspiration [97]. K_c data for various crops are shown in Table 9 [97,107–111].

The water-use efficiency (WUE), also shown in Table 9 [82,112–115], is used as a second indicator in this study for evaluating the agricultural productivity and water resource utilization, as also suggested by Dornburg et al. [82]. The performance of the bioenergy chains in relation to water quantity focuses on use of water by the energy crops, in line with the studies from Smeets et al. and Dornburg et al. [62,82]. Water use related to the processing facilities is limited for the bioenergy chains investigated and will not be further discussed in this study.

Chemical contamination of water streams and underground aquifers with residues of agrochemical products and fertilizers can have a negative impact on the environment [26]. Cramer et al. [30] propose to report on the responsible use of agrochemicals and to measure the impact of biomass production on the water quality with field tests in the area. The latter is not applicable for this study as we analyze the impacts beforehand. The relative toxicity of agrochemicals is analyzed in Smeets et al. [97] to determine the risk for pollution of agrochemicals from biomass production and, consequently, the environmental risks. The impact of fertilizers on the environment is not mentioned by Smeets et al. [97] or Cramer et al. [30], although this can have an eutrophication effect on the groundwater. This criterion is therefore included in this study, resulting in the following set of criteria to get insight in the possible impact of biomass production and processing on the water quality in the region:

- Limited use of agrochemicals combined with a low toxicity level with indicators: agrochemical input and their water solubility and toxicity level;
- Limited impact of fertilizers on the water quality with indicator: N_2O–N emissions from leaching.

The risk for water contamination in the processing industry in the region is expected to be limited due to existing legislation [116–118] and will not be further discussed in this study.

4.6.1. Performance of bioenergy chains in relation to water quantity

The K_c factors in Table 9 show that switchgrass has a larger water need over its growing period compared to soybeans. This is confirmed by Hall [119] mentioning that the evapotranspiration rate of switchgrass is expected to be higher compared to traditional annual crops due to its fast growth, large leave area and deep rooting system that leads to a higher rainfall interception. As a result, deep percolation and runoff of water to groundwater reservoirs, streams and rivers from areas under energy grass cultivation is reduced compared to annual crops. This may lead to a reduction or depletion of these water bodies.

Fig. 14 shows that the risk for water shortages in La Pampa province for soybean and switchgrass production is limited over

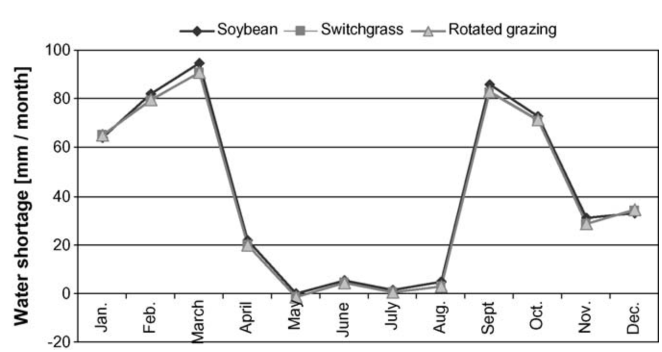


Fig. 14. Calculated monthly water shortages in mm/month, indicated as (WS), for soybean and switchgrass production for bioenergy and, as reference, for rotated grazing, a negative WS indicates a water shortage.

[9] ET_0 is the evapotranspiration for a well-managed (disease free, well-fertilized) hypothetical grass species grown in large fields and for which water is abundantly available [97].
[10] Note that the comparison based on the Kc, indicates the relative difference in water demand under non-water limited conditions, rather than the actual water use [97].

the year. The seeding, growing and harvesting period for soybeans [120] and switchgrass [121] and the high water need of both crops [43,109] during the mid and late growing stage is in general in line with the precipitation pattern in La Pampa province. Intermittent periods of low rainfall can create, however, short water shortages. This may have an impact on the yields attained [26,43,122] and may increase temporarily the risk for water depletion in the drier areas.

Specific data for the WUE of switchgrass are not available. WUE data for miscanthus are therefore used as a reference. Miscanthus has the capacity for high yields on relatively poor quality sites, where water availability would prevent successful production of conventional crops [123]. Lewandowski et al. [123] mention that switchgrass can be produced on similar areas as miscanthus or on areas that are too dry for miscanthus production, as switchgrass is considered more drought tolerant than miscanthus.

Although switchgrass uses per ha more water than soybean (see K_c factor), its water-use efficiency (WUE) is significantly higher. Jørgensen et al. [114] indicate that the WUE of C_4 crops (as maize or switchgrass) are about twice that of C_3 crops due to their higher efficiency of photosynthetic conversion. Yu et al. [112] and McLaughlin et al. [101] mention that C_4 plants produce 30% more food per unit of water than C_3 plants and are well adapted to more arid production areas [124].

The WUE figures in Table 9 imply good agricultural management and only a high WUE can be achieved if other factors (e.g. nutrient availability, incidence of pests and diseases, good management) do not limit crop production [125]. For example, the retention of crop residues combined with no-tillage management decreases the soil evaporation rate of soybeans that would normally occur from a bare soil [126]. Combining an agricultural rotation system with direct seeding also promotes a higher WUE value [102].

Based on the results, an indication is given about the relative performance of the bioenergy chains for this principle. No final conclusion can be given as the risk for water shortages largely depends on rainfall and temperature dynamics in La Pampa over time. Some first conclusions can be drawn, though. Sufficient water seems to be available for bioenergy production during most months in the year in the La Pampa province, especially in the S land areas receiving more rainfall than the mS land areas. Switchgrass uses the available water more efficiently than soybean. In case of limitation in water availability during the growing period, switchgrass causes a higher risk for depletion of water resources compared to soybean. However, a shortage in rainfall will also lead to a yield reduction,

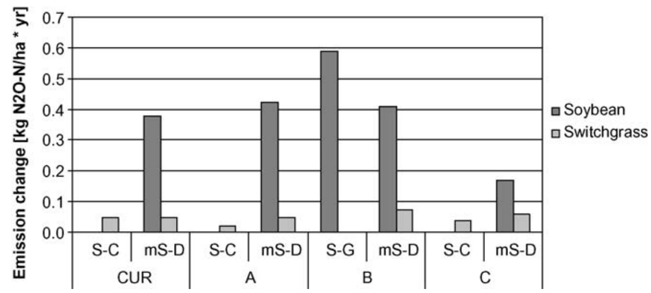


Fig. 15. Change in N_2O–N (in kg/ha/year) emissions from leaching from switchgrass and soybean production for bioenergy compared to the reference land-use system for current situation and for scenarios A, B and C for 2030.

limiting the risk for water depletion. Proper management and adequate monitoring can further reduce this risk. Environmental friendly and advanced techniques for efficient water use are especially promoted in scenarios B and C.

4.6.2. Performance of bioenergy chains in relation to water quality

The fertilizers used for the bioenergy chains are nitrogen and phosphorus fertilizers [6]. Phosphorus is not very soluble and mobile in a soil solution, in contrast to nitrogen [127]. No N fertilizer is applied for soybean production in the current situation. A small increase in N and P fertilizer is assumed for the scenarios A, B and C in 2030 [6]. Switchgrass uses more fertilizers, especially N fertilizer, in the cultivation process compared to soybean cultivation [6]. The low fertilizer inputs for soybean production can however be questioned for the current situation, as discussed in Section 4.5. Fig. 15 shows the change in N_2O–N emissions from biomass production compared to the reference land use (see also Section 4.1). Emissions from nitrate leaching are lower for soybean production than for switchgrass production, when abandoned cropland is used (CUR-S-C, A-S-C, and C-S-C). Nitrate leaching increases significantly for soybean production when replacing degraded or non-degraded grassland due to changes in soil carbon, resulting in N_2O–N emissions. Emissions from nitrate leaching for switchgrass production are limited and mainly a result of nitrogen fertilizer inputs.

The risk of water contamination is higher for agrochemicals than for fertilizers as measurements show that only a limited percentage of the agrochemicals used reach the intended source and the rest spreads to other sources [127]. So far no such

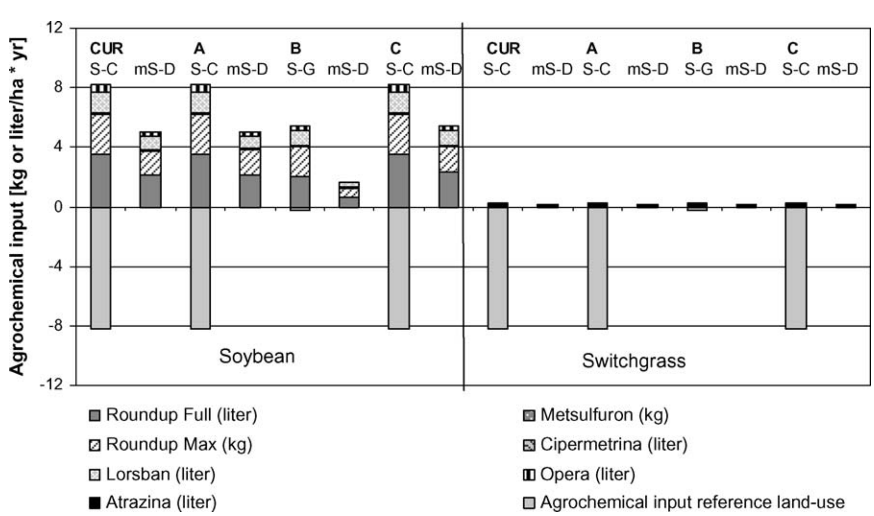


Fig. 16. Change in agrochemical input for soybean and switchgrass production for bioenergy compared to reference land-use system in liter/ha or in kg/ha for current situations and for scenarios A, B and C for 2030.

Table 10
Water solubility and possible environmental risks related to herbicides and pesticides use.

Product	Water solubility		Environmental risks
	mg/l	mg/l	
Opera[a]	20 [130]		No information found
Metsulfuron	2790 [130]	9500 [131]	Low level of toxicity for fish and birds [127]. High to moderate toxicity for algae and aquatic plants [130]
Glysophate[b]	10500 [130]	900000 [131]	Virtually not toxic for bees, very little toxic for birds and fish [127]
Cipermetrina	0.009 [130]	0.004 [131]	Moderately toxic for bees, not toxic for birds, highly toxic for fish [127]
Lorsban[c]		4 [131]	Highly toxic to aquatic organisms on an acute basis in most sensitive species. Moderately toxic to birds on an acute or dietary basis [129]
Atrazina	35 [130]	33 [131]	Low to average (depending on brand) toxicity on birds, fish, bees and aquatic plants [127,130]

[a] Based on pyraclostrobin (main component).
[b] Main component of Roundup.
[c] Common name is Chlorpyrifos.

contamination has been recorded for the Pampas but research on this subject is limited [26]. Fig. 16 shows that the agrochemicals use for switchgrass cultivation is limited as it is used only during the establishment period and removal of the plantation. The use of herbicides and pesticides for soybean production, used on an annual basis, is substantially higher. Several studies mention that the increased weed resistance of soybeans leads to an increased use of glysophate, combined with other herbicides [128].

Table 10 [127,129–131] shows the water solubility and possible environmental risks related to herbicides and pesticides used for soybean and switchgrass cultivation. Highly soluble pesticides (metsulfuron and glysophate) are more likely to be removed from the soil by runoff or by moving below the root zone with excess water [131]. Glysophate has no risk to disturb the fauna [127]. Metsulfuron, used on limited scale for soybean production, may have an average to high risk to disturb aquatic plants [130]. Atrazina, used for switchgrass production, has a low water solubility and, a low to moderate risk to disturb the fauna [127,130].

The change in N fertilizer and agrochemicals use are indicators to measure the relative performance of the bioenergy chains for this criterion. Within this context, agrochemicals use has in this study a higher rating (1.2:1) than fertilizer use due to its higher risk for water contamination. The highest[11] score, defined as an annual decrease in fertilizer and agrochemicals use of 5 units/ha or more compared to the reference system, is estimated when switchgrass is produced on abandoned cropland. The lowest score, with an annual increase in fertilizer and agrochemicals use of 5 units/ha or more compared to the reference system, is estimated when soybean production replaces degraded or non-degraded grassland, with the exception of (B-mS-D).

4.7. Principle 7: biomass production and processing and air quality

This principle aims to minimize air emissions with regard to biomass production, biomass processing and waste management. Compliance with national law and regulations is required [30]. The risk for air and waste contamination in both bioenergy chains is limited as no dangerous materials or rest products are produced or emitted to the air during the processing stages. Beside, national laws and regulations [132–134] are in place. The risk for undesirable air emissions due to bioenergy production and processing is therefore considered insignificant.

4.8. Principle 8: production of biomass and local prosperity

The starting point of this principle is that biomass production contributes to the local economy. Cramer et al. [30] propose to report on this principle according to the following indicators of the Global Reporting Initiative (GRI):

- EC1: Direct economic values that have been generated and distributed (revenues);
- EC6: Policy, methods and part of expenditure with respect to locally based suppliers;
- EC7: Procedures for local staff recruitment and share of the top executives originating from the local community at significant locations of operation;

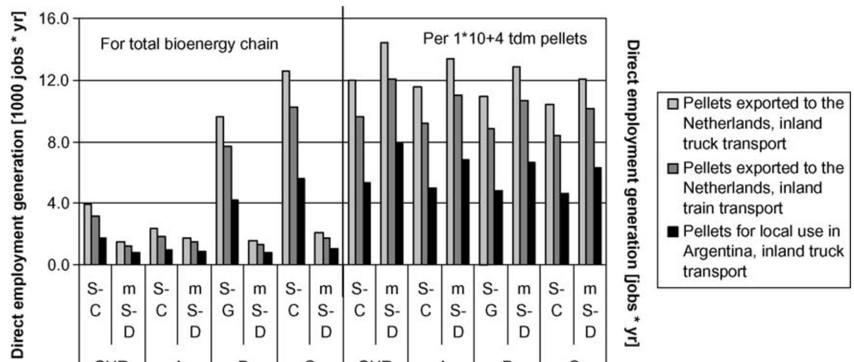
Choices on expenditure of income (EC6) and human resource management (EC7) largely depend on the company to be established. It is therefore not possible to analyze these indicators beforehand. It is, however, possible to give beforehand an indication of the generated revenues from bioenergy production to the local economy (EC1). The socio-economic impacts of export-oriented bioenergy production in Argentina have been analyzed by Wicke [135] with the use of an input–output model and focusing on the variables GDP, trade and employment (direct and indirect). Smeets et al. [97] looked at the contribution of bioenergy production to local employment by analyzing historical trends in employments and wages with the use of statistics.

In this study, the following indicators are used to analyze the impact of biomass production on local prosperity: (i) direct and indirect employment generation in the bioenergy chains and (ii) GDP impact of bioenergy production. The direct employment generation can be calculated with labour input data [6] for the different processing steps in the bioenergy chain for the current situation and for scenarios A, B and C for 2030. Scenarios B and C assume an increase in labour efficiency compared to the current situation, with the strongest increase for scenario C. An indication of the indirect employment and GDP generation from bioenergy production is based on literature sources and on data from Wicke [135].

4.8.1. Local prosperity generated in the switchgrass bioenergy chain

Fig. 17 (left) shows the estimated total direct employment generation generated for the switchgrass bioenergy chain. This ranges from 1.5×10^3 jobs per year for (CUR-mS-D), with 1.0×10^6 tdm pellets generated per year, to 12.6×10^3 jobs per year for (C-S-C) with 12.1×10^6 tdm pellets generated per year. Although scenarios (B-S-G) and (C-S-C) generate a high level of direct employment in case the available potential is fully utilized in the bioenergy chain (Fig. 17 left), the agricultural intensification and higher yields in these scenarios results in a decrease in jobs (in jobs/tdm pellets) compared to the current situation and scenario A (see Fig. 17 right). The same reasoning can be followed when comparing the direct employment generation on *S* land and on mS land. As shown in Fig. 17, inland transport by truck creates more employment than inland transport by train.

[11] Other scores: +: annual decrease in fertilizer and agrochemicals use of 0–5 units/ha compared to reference system. −: annual increase in fertilizer and agrochemicals use of 0–5 units/ha compared to reference system.



* Total biomass potential in tdm pellets/yr: (CUR-S-C) $3.3*10^6$, (CUR-mS-D) $1.0*10^6$, (A-S-C) $2.0*10^6$ (A-mS-D) $1.3*10^6$, (B-S-G) $8.8*10^6$, (B-mS-D) $1.2*10^6$, (C-S-C) $12.1*10^6$ (C-mS-D) $1.7*10^6$

Fig. 17. (Left) Estimated direct employment generation in 1000 jobs per year in the total switchgrass bioenergy chain*. (Right) Estimated direct employment generation in jobs per year per 1×10^4 tdm pellets. The results are calculated for the current situation and for scenarios A, B and C for 2030.

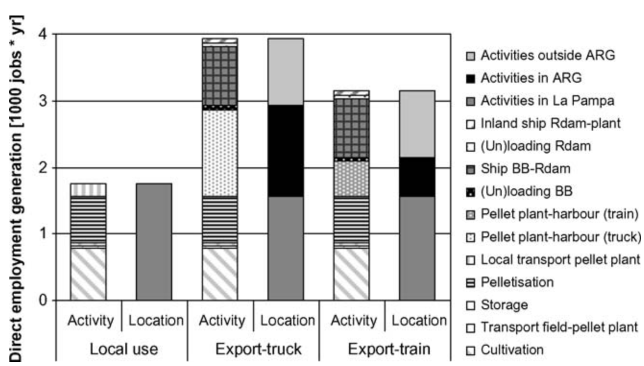


Fig. 18. The distribution of the jobs generated per activity and per geographical location for the total estimated direct employment generation in 1000 jobs per year for the switchgrass bioenergy chain for (CUR-S-C) for local use and for export of pellets to Rotterdam (with train or truck for inland transport) for total pellets produced.

Wicke [135] has estimated the total employment generation (direct and indirect) for an Eucalyptus pellet production chain (chain 1) and a Eucalyptus pellet FT production chain (chain 2). The results show that, beside the direct employment generation from these chains (23%), a substantial amount of extra jobs can be generated by indirect employment (30–31%) and induced impacts (46–47%). The high share of indirect impacts is explained by the large amount of machinery and equipment needed for pellet production. When using these percentages [135] for the switchgrass bioenergy chain, an additional indirect employment generation of 1.9×10^3 (CUR-mS-D) to 16.4×10^3 (C-S-C) jobs/year can be expected.

The export bioenergy chains generate for (CUR-S-C), with 3.3×10^6 tdm pellets generated per year, 40–49% of the total direct employment in La Pampa province (see Fig. 18). The remaining employment, mainly generated in the transport sector, is located in Argentina (mainly Buenos Aires province) and outside the country. When the switchgrass pellets are used for local conversion, all direct employment is generated within La Pampa.

The intensification of agriculture in the future may lead to a decrease in jobs.[12] Wicke [135] has estimated that 96×10^3 jobs are lost in chain 2, due to agricultural intensification. This loss of jobs in the traditional agricultural sector is, however, by far compensated by an increase of 296×10^4 jobs in the new economic activity of bioenergy production from Eucalyptus pellets.

[12] As example: a yield increase from 3.7 to 8.9 tdm/ha is assumed for grain production from 2001 to the year 2015. An increase of feed crops use of 6–17.5% from 2001 to 2015 is assumed for the mixed livestock system.

Within the export chains for (CUR-S-C) cultivation, pelletisation and transport from the pellet plant to the harbour contribute respectively 20–44%, 18–39% and 17–33% to the total employment generated. Switchgrass cultivation and truck transport generate many jobs because of the high volumes of biomass produced. Large inland distances are another factor for employment generation. Employment generation in the conversion step is not included in this study. The FT/pellet sector contributes in Wicke [135] around 3% to the total employment generation in the bioenergy chain. Employment generation in the conversion process is therefore expected to be limited.

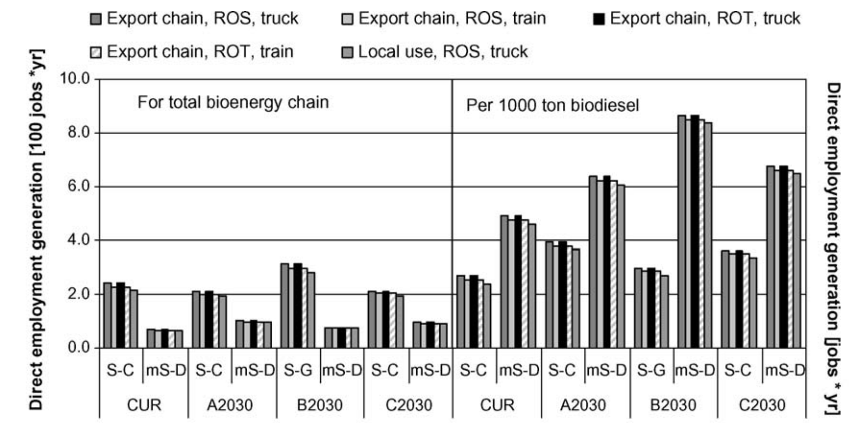
Switchgrass bioenergy chains, including the required infrastructure and pellet plants, are not yet developed in Argentina [6]. Investments in this field therefore contribute to the development of a new economic activity. Wicke [135] estimated that the percentual increase in GDP in 2015 (the moment when the bioenergy chains are fully developed) is 21% for chain 1 and 27% for chain 2 compared to the reference situation in 2001. Imports increase with 24% and 44% for chains 1 and 2. Although the imports are large compared to the reference situation in 2001, they are small related to the exports. Exports in chain 1 are more than four times higher than the imports. Exports in chain 2 are more than 12 times higher than the imports.

Based on the results, an indication can be given about the relative performance of the switchgrass bioenergy chain for this principle which is based on the direct employment generated. It is assumed that the relatively changes in direct employment are in line with expected contributions of the bioenergy chain to GDP and to indirect employment. The highest score, with more than 2000 extra-generated jobs per year due to the introduction of the bioenergy chain as included in this study, is estimated when switchgrass is produced on *S* land. A relatively high score, with more than 200 generated jobs per year due to the introduction of the bioenergy chain as included in this study, is estimated when switchgrass is produced on mS land. Note that the number of jobs generated depends to a large extent to the amount of pellets produced in the switchgrass bioenergy chain, which varies per scenario.

4.8.2. Local prosperity generated in the soybean bioenergy chain

Fig. 19 (left) shows the estimated total direct employment generation generated for the soybean bioenergy chain. This ranges from 58 jobs per year for (CUR-mS-D), with 1.4×10^4 ton biodiesel generated per year, to 312 jobs per year for (B-S-G) with 10.4×10^4 ton biodiesel generated per year.

Although (B-S-G) generates a high level of direct employment in case the available potential is fully utilized in the bioenergy chain



* Total biomass potential in ton biodiesel * yr: (CUR-S-C) 9.0*10^4, (CUR-mS-D) 1.4*10^4, (A-S-C) 5.3*10^4 (A-mS-D) 1.9*10^4, (B-S-G) 10.4*10^4, (B-mS-D) 0.9*10^4, (C-S-C) 5.8*10^4 (C-mS-D) 1.4*10^4

Fig. 19. (Left) Estimated direct employment generation in 100 jobs per year in the total soybean bioenergy chain*. (Right) Estimated direct employment generation in jobs per year per 1×10^3 ton biodiesel. The results are calculated for the current situation and for scenarios A, B and C for 2030. Biodiesel processing is in Rosario (ROS) or in Rotterdam, the Netherlands (ROT). Inland transport in Argentina is by truck or by train.

(Fig. 19 left), agricultural intensification and higher yields results in a decrease in jobs (in jobs per ton biodiesel) compared to the current situation (see Fig. 19 right). The same reasoning can be followed when comparing the direct employment generation on *S* land and on mS land. Inland transport by truck creates more employment than inland transport by train. The soybean bioenergy chain (whole crop) for export generates slightly more employment (3–12% for truck chains) than the chains for local use. This extra employment is generated outside the country (see Fig. 20).

Llach et al. [136] have estimated that the chain 'vegetable oil and subproducts' generated around 288×10^3 jobs in Argentina in 2004, compared to 230×10^3 for the milk chain and 543×10^3 jobs for the meat chain. The Ministry of Economy [137] has estimated that every direct job generated in soybean value chain multiplies to 17.7 indirect jobs. In comparison: one direct job in the petroleum, meat or milk sector multiplies to 10.6, 5.5 and 6.1 indirect jobs, respectively.

Cultivation contributes 14–32% (whole crop) to the total direct employment in jobs per year in the export chain (truck-Rosario). This contribution is 29% in (CUR-S-C-truck-ROS) for the whole crop and 17% when employment is allocated to the soybean oil content, used for biodiesel production. The labour input (in hours per tdm) in the cultivation process (whole crop) is limited, ranging from 0.5 for (CUR-S-C) to 0.8 h/tdm for (CUR-mS-D). This number fluctuates per scenario because of differences in yield and in efficiency. The required labour input for soybean production is discussed by Berkum et al. [84], mentioning that large agricultural farms in Argentina with highly mechanized soybean production combined with direct seeding, generate around one labour place for every 200 hectares. In comparison, small traditional farms practicing rotation with two crops generate around one labour place for every eight hectares. The low labour input for intensive soybean production generates a process of rural out-migration compared to more traditional production systems, destabilization of livelihoods and scarcity of jobs in the agricultural sector in the Pampas region [27,84].

The contribution of processing activities to the direct employment generation in the soybean bioenergy chain is limited, namely 15–18% (whole crop) for the scenarios shown in Fig. 19. The biodiesel plants do not need many operators. They do, however, generate a demand in services that are supplied by regional companies. The biodiesel sector employed around 5×10^3 people in 2008 (direct and indirect labour) and the sector is estimated to create $60–70 \times 10^3$ jobs in the coming 15 years [138]. Truck transport from the field to the crushing plant contributes significantly to the total employment generation when looking at the whole crop (45–58% for scenarios in Fig. 19) due to the large product volumes that need to be handled in the beginning of the chain. This contribution reduces, however, significantly when only

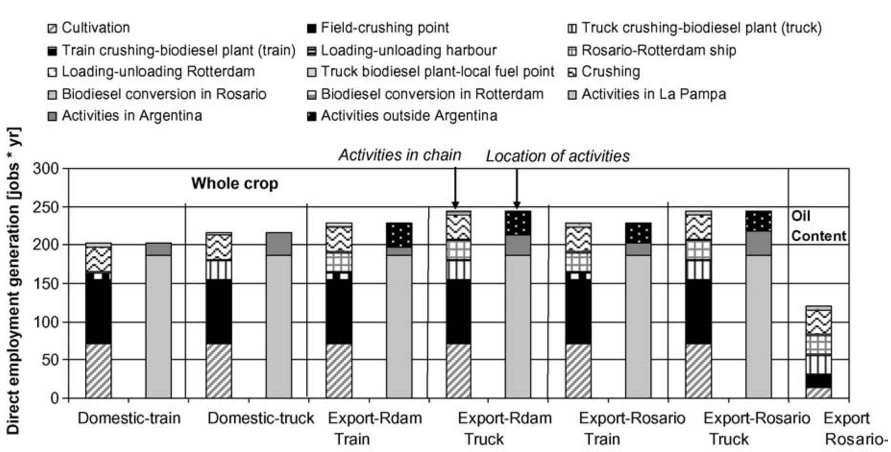


Fig. 20. The distribution of jobs generated per activity and per geographical location for the total estimated direct employment in jobs per year for the soybean bioenergy chain for (CUR-S-C) for local use and for export (with biodiesel processing located in Rosario or in Rotterdam) for inland truck or train transport, for total biodiesel produced.

Table 11
Criteria and indicators for principle production of biomass and contribution to social well-being as proposed by Cramer et al. [30].

Criteria	Indicator
1. No negative effects on human rights	Recognition Universal Declaration of Human Rights
2. No negative effects on the working conditions of employees	Compliance of Tripartite Declaration of Principles Concerning Multinational Enterprises and Social Policy
3. The use of land must not lead to the violation of official property and use	Guarantee of right indigenous people. Land-use must be regulated by state
4. Positive contribution to the social well-being of the population	Social indicator 1 of GRI: nature, scope, and effectiveness of any programs and practices that assess and manage the impacts of operations on communities
5. Insight into possible violations of the integrity of the company	Social indicator 3 and 4 of GRI: Percentage of employees trained in organization's anti-corruption policies and procedures and actions taken in response to incidents of corruption.

the soybean oil content, used for biodiesel production, is considered (see example in Fig. 20).

The soybean chain is an existing activity in Argentina. A value of 13.5 million US$ was exported in 2007, from which the state received 4.4 million US$ [139]. Investments reached 750 million US$ in the year 2005–2007. From 2006 onwards, the biodiesel industry contributed significantly to these investments [139]. Companies have invested 585 million US$ in biodiesel projects in Argentina in 2007 and additional investments, which are used to increase the capacity of crushing and biodiesel plants, of 800 million US$ were expected end of 2007 [140]. Capital costs generated in the soybean bioenergy value chain are thus mainly invested in a further extension of the required infrastructure of an already existing chain.

Based on the results, an indication is given about the relative performance of the soybean bioenergy chain for principle 8. No scenarios have the highest score (see also Section 4.8.1). A high score, with more than 200 generated jobs per year due to the introduction of the bioenergy chain as included in this study, is estimated when soybean is produced on S land. Scenarios, with 0–200 generated jobs per year due to the introduction of the bioenergy chain as included in this study, have a neutral score as this amount of jobs is considered to contribute relatively little to local welfare in the region.

4.9. Principle 9: contribution to social well-being from biomass production

Cramer et al. [30] translate this principle into five criteria. The criteria and indicators are shown in Table 11. As criteria 4 and 5 largely depends on the company to be established, it is not possible to estimate the performance for the associated indicators beforehand. Criterion 1 (no negative effects on human rights); criterion 2 (no negative effects on the working conditions of employees) and criterion 3 (the use of land must not lead to the violation of official property and use) will be discussed in this study.

4.9.1. Social well-being for the switchgrass and soybean bioenergy chain

The Universal Declaration of Human Rights, criterion 1, is recognized by Argentina [141]. Violations against human rights related to the working conditions of employees and child labour are not an issue in Argentina [27].

The recognition of the Tripartite Declaration of Principles, criterion 2, by companies is stimulated by the Argentinean government [142]. The Argentinean government itself has subscribed the OECD guidelines for multinational enterprises[13] [143].

[13] The OECD Guidelines for Multinational Enterprises are recommendations addressed by governments to multinational enterprises, providing voluntary principles and standards for responsible business conduct consistent with applicable laws.

The Ministry of Labour has established the ''Network for Corporate Social Responsibility and Decent Work'' to promote Corporate Social Responsibility. This network of companies signed a Commitment to Corporate Social Responsibility and Decent Work in 2007 [142].

Rural work conditions in Argentina are regulated by specific resolutions. The 'Rural Worker License law' aims at regulating different aspects of the hiring process of permanent, temporary and harvest workers in the agricultural sector. The National Record Office of Rural Employers and Workers is established in 2001 to combat informal employment and to increase protection of workers [27]. Literature sources show variable estimations about the amount of informal workers (with no to limited access to insurance) and formal workers in agriculture in Argentina. Accurate statistical data are difficult to obtain. Unofficial estimations range from 17.5% to 50% of the workers in the agricultural sector engaged in formal employment [27,144,145].

Land use rights, criterion 3, are officially laid down and described in Argentina. Land property in La Pampa province is largely regulated through private ownership or tenure of land. Limited areas of land are publicly owned (see also Section 4.3). In case the land is rented there are basically two forms of contracts [146]. The first form is a contract in which the owner charges a fixed amount per year or per harvest. The second form is that the owner receives a certain percentage of the production obtained by the tenant.

Based on criteria 1–3, no negative impacts from biomass production on the social well-being can be expected and, if properly managed, positive impacts can be generated. The latter is more probable in scenarios B and C, characterized by a stronger socio-environmental awareness and economy.

5. Synthesis of the environmental and socio-economic performance of the bioenergy chains

The relative performance of the environmental and socio-economic impacts of the bioenergy chains is summarized in Table 12, showing that the impacts can vary strongly between scenarios for both bioenergy crops depending on the underlying assumptions. Some conclusions can be drawn:

- Most environmental benefits can be achieved when switchgrass is produced on abandoned cropland;
- Switchgrass production replacing degraded grassland, limiting the competition with food and feed production, also shows a good overall sustainability performance, especially for scenarios (B-mS-D) and (C-mS-D).
- Soybean production for bioenergy shows a good overall sustainability performance if produced on abandoned cropland (A-S-C, C-S-C, and CUR-S-C). The production of soybean on degraded grassland results in a relatively lower sustainability performance;

Table 12
Rough indication of relative sustainability performance of switchgrass and soybean bioenergy chain based on the expected environmental and socio-economic impacts of the bioenergy chains when developed in La Pampa province (Argentina) for the current situation and for scenarios A, B and C to the year 2030 (+, high score; −, negative score, 0, neutral score; ++, very high score; −−, very low score; ≈, expectation with significant range of insecurity).

Principles	Switchgrass bioenergy chain								Soybean bioenergy chain							
	CUR		A		B		C		CUR		A		B		C	
	S	mS	S	mS	S	mS	S	mS	S	mS	S	mS	S	mS	S	mS
Reference land-use[a]	C	D	C	D	G	D	C	D	C	D	C	D	G	D	C	D
1 – Soil carbon balance[b]	++	+	++	+	+	+	++	+	0	−−	0	−−	−−	−−	0	−
2 – GHG balance[c]	++	++	++	++	++	++	++	++	++	+	++	+	+	0	++	+
3 – Land-use change																
Change in land-use[d]	≈0+	≈0+	≈0+	≈0+	≈0+	≈0+	≈0+	≈0+	≈0 −	≈0 −	≈0	≈0 −	≈0 −	≈0 −	≈0 −	≈0 −
Rise land prices[e]	0	0	−	0	+	0	+	0	0	0	−	−	0	0	−	−
Rise food prices	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0	≈ 0
4 – Biodiversity[f]	+	0	+	0	−	0	+	0	0	−	0	−	−	−	0	−
5 – Soil quality																
Soil erosion[g]	++	++	++	++	−	++	+	++	0	−	0	−	−−	++	0	++
Soil nutrients[h,i]	≈++	≈+	≈++	≈+	≈+	≈+	≈++	≈+	≈0/−	≈ −−	≈0	≈ −−	≈ −−	≈ −−	≈0	≈−
6 – Water quality	++	+	++	+	−	+	++	+	0	−−	0	−−	−−	−−	0	−−
Water quantity [j]	≈ 0+	≈ 0−	≈ 0+	≈ 0−	≈ 0+	≈ 0	≈ 0+	≈ 0	≈ 0	≈ 0−	≈ 0	≈ 0−	≈ 0+	≈ 0−	≈ 0+	≈ 0−
7 – Air quality	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 – Local prosperity[k]	≈++	≈+	≈++	≈+	≈++	≈+	≈++	≈+	≈+	≈0	≈+	≈0	≈+	≈0	≈+	≈0
9 – Social well-being	0	0	0	0	+	+	+	+	0	0	0	0	+	+	+	+

[a] Reference land-use: G, non-degraded grassland; C, cropland; D, degraded grassland.
[b] (++) carbon benefit >0.6 ton C/ha/year; (+) carbon benefit >0 and <0.6 ton C/ha/year; (0) carbon benefit = 0 ton C/ha/year; (−) carbon benefit <0 and >−0.6 ton C/ha/year; (−−) carbon benefit <−0.6 ton C/ha/year.
[c] (++) GHG reduction potential is >85%; (+) GHG reduction potential is >35% and <85%, for lifetime period of 20 years.
[d] (+) Expected softening effect on ongoing land-use change of conversion of pasture areas to cropland areas; (−) strengthening effect on ongoing land-use changes. Ongoing land-use change.
[e] (+) Decrease in land price compared to current situation; (−) increase in land price compared to current situation.
[f] (+) Positive MSA value; (0) MSA value is zero; (−) negative MSA value.
[g] In changes in annual soil loss compared to reference land-use system: (++) Soil loss decreases >2 ton/ha/year; (+) Soil loss decreases >0 and <2 ton/ha/year; (0) no changes in annual soil loss; (−) soil loss increases >0 an <2 ton/ha/year; (−−) soil loss increases >2 ton/ha/year.
[h] See footnote b).
[i] In change in fertilizer and agrochemical use compared to reference land-use system: (++) Annual decrease of 5 units/ha; (+) annual decrease of >0 and <5 units/ha; (0) no change in fertilizer and agrochemical use; (−) annual increase of >0 and <5 units/ha; (−−) annual decrease of >5 units/ha.
[j] (+) Environmental friendly and advanced techniques for efficient water use are applied in scenario; (−) Possible risk for water depletion in drier areas.
[k] In extra generated jobs per year due to introduction of biomass energy chain: (++) >2000 extra generated jobs; (+) >200 and <2000 extra generated jobs per year; (0) >0 and <200 extra generated jobs. (+) Expectation of possible positive impacts on social well-being in scenarios with stronger socio-environmental awareness and economy; (0) recognition of Universal Declaration of Human Rights, Tripartite Declaration of Principles and land-use rights.

- Bioenergy production on non-degraded grassland, especially from soybean production, may result in negative environmental impacts.
- Excluding the non-sustainable scenarios, being (CUR-mS-D, A-mS-D, B-mS-D, C-mS-D) for soybean production for bioenergy and (B-S-G) for both crops, the potential availability of land for the bioenergy crops production in La Pampa province on *S* and mS land ranges from 0 to 24 $\times$ 10^4 ha (instead of 17–30 $\times$ 10^4 ha) for soybeans and from 17 to 97 $\times$ 10^4 ha for switchgrass (instead of 37–97 $\times$ 10^4 ha) [6]. The upper limit for switchgrass production for energy remains constant as the scenarios with a high potential are also the scenarios with a good sustainability performance;
- When excluding the non-sustainable scenarios, soybean biodiesel production costs are competitive with fossil fuel costs when oil has a price of 80–183 US$/barrel for the export chains (instead of 80–238 US$/barrel) and a price of 55–122 US$/barrel for local use (instead of 55–176 US$/barrel), depending on the scenario. Ergo, the non-sustainable scenarios are also the more expensive scenarios for soybean bioenergy production;
- When excluding scenario (B-S-G), there are no changes in the economic competitiveness from electricity from switchgrass pellets with the cost price of electricity from coal in the Netherlands. The use of switchgrass pellets for local energy production on the short-term is economically not viable due to current low natural gas prices [6];

The results in the various scenarios show that most socio-economic and environmental benefits can be achieved when a bioenergy production chain aims to use the most advanced agricultural production system available in technical and environmental terms, replacing the land use system in the region with the lowest economic and environmental performance while preventing leakage.

The overall performance of the bioenergy chains is in general higher for switchgrass than for soybeans. It is possible to significantly minimize the environmental impacts (especially the risk of leakage in land use and biodiversity changes) from the soybean bioenergy chain when the generated feed is used explicitly for livestock production in the region. The surplus land can then be used for alternative purposes such as nature regeneration or biomass production. Modernising simultaneously biomass production for energy and food to prevent competition for land is needed to attain most socio-economic and environmental benefits from bioenergy production [86]. The need and possibilities to diminish competition on agricultural land in Argentina by e.g. intensification and introduction of new species is mentioned by various authors [24,147–149]. Land use regulation and planning by the government in cooperation with the actors involved is in this case desired [147].

6. Summary and conclusions

A combination of quantitative and qualitative indicators has been used to get an indication of the socio-economic and environmental performance of bioenergy production in the province La Pampa in Argentina. Qualitative indicators were used for the principles 3 (not endanger food supply and local applications) and 9 (contribution to social well-being) that lack an appropriate methodology or dataset to quantify the performance.

The use of standardized methodologies is desired but not yet possible for all principles, as shown in Table 13. No appropriate methodology was available to couple macro-economic drivers with micro-economic impacts. The available methodologies to assess the impacts of biomass production on water depletion and on soil quality require further elaboration to be applicable on a regional level for a range of biomass resources.

A norm or standard has to be set for the criteria used to interpret and score the obtained results in terms of absolute performance. This standard is available for biodiversity (the MSA values) and for the GHG emission reduction that should be achieved (e.g. at least 35% GHG emission reduction compared to the reference case) but is at present lacking for other criteria. In our assessments, the scores for other principles are therefore based on a relative and not absolute performance of the bioenergy chains.

Table 13
Overview of the indicators, data needs and methodologies used to analyze – based on a set of nine principles – the socio-economic and environmental performance of bioenergy chains. Future needs and options for improvement are given in the last column.

Principle	Methodology used	Data		Performance indicator	Future needs and options for improvement
		Need	Availability		
1. Carbon stock changes	IPCC methodology [31]	High	Yes (mainly default values)	Δ ton C/ha/year	Need for local data, better insight in relation carbon stock changes with management system, land-use changes, land suitability.
2. GHG balance	IPCC methodology [31]	High	Yes (partly default values)	GHG reduction in %	Improvement insecurity default values (N_2O emissions); need to collect local data and EF by-products.
3. Changes in land-use, prices	Reporting on land prices, food prices, land ownership and expected land-use changes in relation with current ongoing trends	Average	Yes (statistics, expert knowledge)	Land price	Not possible to draw a final conclusion ex ante. Methodology for qualitative indicator needs to be developed further.
				Food price Land ownership Expected land-use change	
4. Biodiversity	Total biodiversity assessment: Exclusion HCV areas + contribution bioenergy production to agro-biodiversity	Average	Yes (maps, legislation, empirical data)	Exclusion HCV areas	Stakeholder approach [85] requires more time. Field studies on relation local agro-biodiversity and biomass production.
				MSA values	
5a. Soil quantity	USLE equation	Average	Yes (partly default values)	Soil loss in ton/ha/year	More accurate data for management factor agricultural systems. Wind erosion is not included in USLE equation
5b. Soil quality	Carbon stock change, as an indicator for SOM	High	Based on calculated results Section 4.1	Δ ton C/ha/year (indicative)	Lack of accurate local data (crop recovery, nutrient composition crop) for simple nutrient balance equation. Standardized nutrient-balance model to be developed based on limited set of input data.
6a. Water quantity	Simple water balance and WUE	Average	Low (default values)	Water shortage (WS) in mm/month WUE in g dm/kg water	Not possible to draw conclusion ex ante. Insight in dynamics local factors, climate, and energy crop characteristics needed by data collection and local measurements.
6b. Water quality	The water solubility and toxicity level of the inputs (fertilizers, agrochemicals) used for bioenergy production	Average	Yes (partly based on calculated results)	N_2O–$N_{leaching}$/ha/year	Local measurements needed for better insight in risk water contamination due to inputs. Standardized methodology and indicator needed based on limited set input data.
				Agrochemicals input in unit/ha/year, their toxicity and solubility level in mg/l	
7. Air quality	Compliance with legislation	Low	Yes	Compliance legislation	Qualitative indicator and methodology desired if air contamination is expected.
8. Local prosperity	Expected direct employment in bioenergy chains	High	Based on own calculations	Jobs/year	More insight needed in contribution bioenergy production to GDP and indirect employment.
9. Social well-being	Reporting on land-use rights and recognition declarations based on current situation	Average	Descriptive	(a) Recognition Declaration of Human Rights; (b) Recognition Tripartite Declaration; (c) Description land-use rights	Final conclusions cannot be drawn ex ante whether a biomass project itself will contribute or not.

The type (default data, local data, expertise, maps) and level of accuracy of input data that is available varies strongly between the principles investigated. This indicates that the results in Table 12 should be used with caution.

The results in Table 12 show, however, also that it is possible to give a rough indication which chains and scenarios are expected to perform more sustainable than others. The use of scenarios enables to show the wide range in results that can be obtained due to variations in agricultural management systems, land suitability, reference land use systems, lifetime periods investigated, allocation of impacts and the impact of indirect land use changes. The approach gives an understanding of the complexity of bioenergy chains and the underlying factors influencing the GHG balance and other sustainability issues. Note for example that the reference land use system 'cropland' in this study is based on soybean production and that the choice for an alternative crop may significantly change the results. Key determinants for the sustainability of bioenergy production systems are the reference land use, the selection of the bioenergy crop suitable to the agroecological zone, and the management system that is used.

This also implies that it is possible to steer for a large part the sustainability performance of a bioenergy chain during the project development and implementation phase. Demonstration projects that apply a learning-by-doing approach combined with strict monitoring can give more insight in the sustainability performance of bioenergy chains in different regions. Various ongoing initiatives, such as the Roundtable on Sustainable Biofuels or the Roundtable on Responsible Soy, may serve as a suitable international platform to extend the knowledge and experience needed for sustainable bioenergy production. The productive and environmental quality system, developed by AAPRESID [80,150], provides on a national level a sound basis. This system certifies crop production in general based on soil health indicator values and Good Agricultural Practices.

Land use planning plays a key role in this process by setting conditions for biomass production (which crop, land use, management system) in a certain region. This also requires for decision-makers a consideration of the relative importance of each principle as the improvement of one principle can mean a deterioration of the other.

The conclusions also lead to the following recommendations for research:

- Further development and testing of a scenario-based set of socio-economic and environmental impact assessment tools that enables stakeholders to monitor and steer the performance of bioenergy projects;
- Development of a robust approach to weigh the performance of individual criteria;
- Improvement of the analysis of the socio-economic and environmental principles for bioenergy chains on a regional level by field data collection, methodology improvement and insight in interrelations of key underlying factors on various sustainability criteria (see also Table 13);

The need to meet sustainability standards for bioenergy production to compete on the international market is recognized in Argentina [151].

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References

[1] WEA, World energy assessment: energy and the challenge of sustainability United Nations development programme, New York: Bureau for Development Policy, United Nations Department of Economic and Social Affairs, World Energy Council, World Energy Assessment; 2000.
[2] OECD/IEA. World energy outlook. Paris: International Energy Agency, Organisation for Economic Co-operation and Development; 2008, 578 p..
[3] Lewandowski I, Faaij APC. Steps towards the development of a certification system for sustainable bio-energy trade. Biomass Bioenergy 2006;30(2): 83–104.
[4] van Dam J, Junginger M, Faaij A, et al. Overview of recent developments in sustainable biomass certification. Biomass Bioenergy 2008;32(8):749–80.
[5] Smeets E, Junginger M, Faaij A, et al. The sustainability of Brazilian ethanol—an assessment of the possibilities of certified production. Biomass & Bioenergy 2008;32(8):781–813.
[6] van Dam J, Faaij A, Hilbert J, et al. Large-scale bioenergy production from soybeans and switchgrass in Argentina. Part A. Potential and economic feasibility for national and international markets. Journal of Renewable and Sustainable Energy Reviews 2009; in press.
[7] USDA. Land values and cash rents 2007 summary August 2007. Washington: National Agricultural Statistics Service, United States Department of Agriculture; 2007 .
[8] INTA-Anguil. Mapa Vegetación de La provincia de La Pampa, part of presentation from H. Petruzzi on Switchgrass production in La Pampa province. Anguil, Argentina; 2008.
[9] LaPampa, Sintesis socio-economica de La Provincia de La Pampa. Gobierno de La Pampa, Santa Rosa; 2006.
[10] Verna CA, Haydee Durango N, Moralejo RH, et al. Anuario Estadístico de la Provincia de La Pampa 2007. Dirección General de Estadísticos y Censos, Provincia de La Pampa, Santa Rosa, La Pampa; 2007 (258 p.).
[11] LaPampa. Recurso Suelo de La Pampa, Recursos Hidricos Subterreaneas y Ecologia. La Pampa en Crecimiento – Diagnóstico de la Situación. Sitio oficial de La Pampa. Santa Rosa, La Pampa; 2008.
[12] Busso CA. Towards an increased and sustainable production in semi-arid rangelands of central Argentina: two decades of research. Journal of Arid Environments 1997;36(2):197–210.
[13] Bilenca D. Situación de los pastizales en la Región Pampeana y estrategias para su conservación. Programa Pastizales, Fundación Vida Silvestre Argentina (FVSA), Buenos Aires, Argentina; 2005 (3 p.).
[14] CREA. Recuperación de pastizales naturales degradaos. Revista CREA: Intensificación Ganadera; February 2008 Year: 36, 328, p. 64–70.
[15] FVSA. Pastizales: Conservar la biodiversidad de los pastizales pampeanos. Fundación Vida Silvestre Argentina. Buenos Aires, Argentina; 2007.
[16] DRN. Bosques y pastizales. Dirección de recursos naturales. Dirección de recursos naturales—ministerio de la producción, Subsecretaria de asuntos agrarios gobierno de La Pampa. Santa Rosa, Argentina; 2008.
[17] LaPampa. Ley 1321 – Areas protegidas: law requires that areas with a high biodiversity value can be declared and managed as protected areas. Gobierno de La Pampa; 1995. (1321) (3 p.).
[18] Congreso. Ley de Presupuestos Mínimos de Protección Ambiental de los Bosques Nativos. This law 26331 establishes minimum assumptions of environmental protection for enrichment, restauration, conservation, exploitation and sustainable management of native forests, and the environmental services that they provide. Congreso Argentino; 2007.
[19] Moscatelli G, Pazos MS. Soils of Argentina—nature and use. In: International symposium on soil science: accomplishments and changing paradigm towards the 21st century and IUSS extraordinary council meeting; 2000.
[20] INDEC. Censo Nacional Agropecuario (CNA), www.indec.gov.ar/default_cna2002.htm. Instituto Nacional de Estadisticas y Census. 24 November 2008. Buenos Aires; 2002.
[21] Petruzzi H. Discussion with H. Petruzzi (INTA Anguil) on possibilities for (large-scale) biomass production from Switchgrass in the La Pampa province. 30 January 2008. Santa Rosa, La Pampa Province; 2008.
[22] Giai SB, Tullio JO. Características de los principales Acuíferos de La Pampa, available at: http://www.apa.lapampa.gov.ar/Hidrologia/Acuiferos.htm. Facultad de Ciencias Humanas UNL-Pam, Dirección de Aguas de La Pampa. 11 December 2008. Santa Rosa; 2008.
[23] INTA-Anguil. Temperaturas (°C) de la Provincia de La Pampa – Map 7, 2002, Instituto Nacional de Tecnología Agropecuaria Anguil, La Pampa; 2002.
[24] Stritzler NP, Petruzzi NP, Frasinelli HJ. Variabilidad climática en la Región Semiárida Central Argentina. Adaptación tecnología en sistemas extensivos de producción animal. Revista Argentina de Producción Animal 2007;27(2): 111–23.
[25] INTA-RIAP. Informe Mensual de Precipitaciones. Argentina: Instituto Nacional de Tecnología Agropecuaria. Anguil; 2008.
[26] Solbrig OT. Towards a sustainable Pampa agriculture: past performance and prospective analysis, DRCLAS Working Paper No 96/97-6. David Rockefeller Center for Latin American Studies, Harvard University, Cambridge, USA; 1997.
[27] Verner D. Rural poverty and labor markets in Argentina, retrieved 26.01. 2006 from http://siteresources.worldbank.org/INTARGENTINAINSPANISH/Resources/Argentina_Rural_Poverty_Labor_Market_062105_2.pdf. World Bank; 2005.
[28] INDEC. Resultados generales Censo Nacional Agropecuario 2002. ISBN 950-896-365-4. Buenos Aires, Argentina: Instituto Nacional de Estadistica y Censos; 2006.

[29] Iturrioz GM. La Pampa en Cifras: Datos básicos del sistema agroalimentario provincial. Instituto Nacional de Tecnología Agropecuaria, Estación Experimental Agropecuaria Anguil, Anguil, La Pampa province; 2005.
[30] Cramer J, Wissema E, de Bruijne M, et al. Testing framework for sustainable biomass, final report from the project group 'sustainable production of biomass'. The Hague: Project group Sustainable Production of Biomass; 2007 , 72 p..
[31] IGES. 2006 IPCC guidelines for national greenhouse gas inventories, vol. 4, agriculture, forestry and other land use. Institute for Global Environmental Strategies, prepared for the Intergovernmental Panel on Climate Change, Hayama, Japan; 2006.
[32] Voet van der E, Oers van L, Davis C, et al. Greenhouse gas calculator for electricity and heat from biomass. Leiden, the Netherlands: CML Institute of Environmental Sciences, Leiden University; 2008.
[33] Hamelinck C, Koop K, Croezen H, et al. Technical specification: greenhouse gas calculator for biofuels, PBIONL062632/PBIONL081307. Ecofys, Utrecht, the Netherlands; 2008.
[34] Fischer G, van Velthuizen H, Nachtergaele FO, et al. Global agro-ecological zones (global AEZ). Laxenburg, Austria: International Institute for Applied Systems Analysis; 2000.
[35] Tolley-Henry L, Raper-Jr CD. Nitrogen and dry-matter partitioning in soybean plants during onset of and recovery from nitrogen stress. Bot Gazette 1986;147(4):392–9.
[36] Fargione J. Land clearing and the biofuel carbon debt. Science 2008;319: 1235–8.
[37] Searchinger T. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. Science 2008;319:1238–40.
[38] Gnansounou E. Accounting for indirect land use changes in GHG balances of biofuels, Review of current approaches, working paper, REF. 437.101. EPFL-ENAC-LASEN, Lausanne (22); 2008.
[39] Fehrenbach H, Fritsche U, Griegrich J. Greenhouse gas balances for biomass: issues for further discussion, Issue paper for the informal workshop, January 25, 2008 in Brussels. Öko-Institut on behalf of the German Federal Environment Agency, Heidelberg; 2008.
[40] Lewandowski I, Elbersen W. Production and use of PPG—discussion of the state and future needs of research and development. Perennial Rhizomatous grasses for biomass production—options and prospects. In: Workshop at the 1st world conference and exhibition on biomass for energy and industry; 2000.
[41] Liebig MA, Johnson HA, Hanson JD, et al. Soil carbon under Switchgrass stands and cultivated cropland. Biomass & Bioenergy 2005;28:347–54.
[42] Lee DK, Doolittle JJ, Owens VN. Soil carbon dioxide fluxes in established switchgrass land managed for biomass production. Soil Biol Bioechem 2007;39:178–86.
[43] Petruzzi H.In: Presentation on Switchgrass experiment the La Pampa province and possibilities for large scale Switchgrass production in the country for export; 2008.
[44] Bullard M, Metcalfe P. Estimating the energy requirements and CO_2 emissions from production of the perennial grasses Miscanthus. UK: Switchgrass and Reed Canary Grass; 2001.
[45] Zach A, Tiessen H, Noellemeyer E. Carbon turnover and Carbon-13 natural abundance under land use change in Semiarid Savannah soils of La Pampa, Argentina. Soil Sci Soc Am, reproduced from Soil Sci Soc Am J 2006; 70: 1541–46.
[46] Díaz-Zorita M, Duarte GA, Grove JH. A review of no-till systems and soil management for sustainable crop production in the subhumid and semiarid Pampas of Argentina. Soil Tillage Res 2002;65:1–18.
[47] Lamers P. Emerging liquid biofuel markets ¿A dónde va la Argentina? 2006.. Lund, Sweden: University of Lund; 2006.
[48] Hilbert J. Personal communication with J. Hilbert on current soybean research in Argentina, Director Instituto de Ingeniería Rural, IIR, Centro de Investigación de Agroindustria, CIA Instituto Nacional de Tecnología Agropecuaria, INTA. 25 February 2008. Castelar, Argentina; 2008.
[49] EC. Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, COM (2008) 19 final 2008/0016 (COD). European Commission, Brussels; 2008. 60 p.
[50] RPB. Ontwikkeling prijs landbouwgrond met blijvend landbouwkundig gebruik in Nederland 1990-2006, http://www.rpb.nl/nl-nl/Default.aspx?hrf=http%3A%2F%2Fwww.rpb.nl%2Fcontent%2Fcompendium.aspx%3Fpid%3D34%26id%3D3824. Ruimtelijk Plan Bureau. 29 February 2008. The Hague; 2007.
[51] Wicke B, Dornburg V, Junginger M, Faaij A. Different palm oil production systems for energy purposes and their greenhouse gas implications. Biomass & Bioenergy 2008;32(12):1322–37.
[52] RoyalSociety. Sustainable biofuels: prospects and challenges. London: The Royal Society; 2008.
[53] Smeets E, Bouwman L, Stehfest E, et al. The contribution of N_2O to the greenhouse gas balance of first-generation biofuels. Glob Biochemical Cycles 2008;15(1):1–23.
[54] Bauen A. Carbon reporting within the renewable transport fuel obligation—methodology. London: E4Tech in Consultation with the Department for Transport; 2007.
[55] Horne R. Biomitre technical manual, final project report BIOmass-based climate change mitigation through renwable energy (BIOMITRE), Project number NNE-00069-2002. Resources Research Unit, Forest Research, UK; 2004. 55 p.
[56] Fehrenbach H. Greenhouse gas balances for the German quota legislation. Heidelberg: IFEU, Prepared for the Federal Environment Agency Germany; 2007.
[57] Damen K, Faaij A. A greenhouse gas balance of two existing international biomass import chains: the case of residue co-firing in a pulverised coal-fired power plant in The Netherlands. Mitigation Adapt Strategies Glob Change (Special Issue) 2006;11(5–6):1023–50.
[58] Donato LB, Huerga R. Principales insumos en la producción de biocombustibles. Un análisis económico. Balance energético de los cultivos potenciales para la producción de biocombustibles. Instituto Tecnología Alimentos, CIA-INTA Castelar, Buenos Aires; 2007.
[59] Panichelli L. Análisis de ciclo de vida (ACV) de la producción de biodiesel (B100) en Argentina, Facultad de Agronomia, 2006. Buenos Aires: Universidad de Buenos Aires; 2006.
[60] SIMAPRO. Database SIMAPRO Eco-indicator 95 V2.03/Europe g, 2007, SIMA-PRO 7.0; 2007.
[61] Umweltbundesamt. Prozessorientierte Basisdaten für Umweltmanagement-Instrumente (ProBas), http://www.probas.umweltbundesamt.de/php/index.php. Retrieved 12.04.2007. Germany: Umwelt Bundesamt; 2007.
[62] Smeets E, Lewandowski I, Faaij A. The economical and environmental performance of miscanthus and switchgrass production and supply chains in a European setting. Journal of Renewable and Sustainable Energy Reviews 2008;13(6–7):123–1245.
[63] Stuijt N. Personal e-mail communication on density characteristics Roundup with N. Stuijt, Marketing & Sales Manager Monsanto Crop Sciences Nederland B.V on density of Roundup products. 19 August 2008. Utrecht, the Netherlands; 2008.
[64] Hilbert JA, Muzio JJ. INTA IIR-BC-INF-05-08 calculo emisiones biodiesel, Anexo Centro de Investigación de Agroindustria. Buenos Aires, Argentina: Instituto Nacional de Tecnología Agropecuaria, INTA; 2008.
[65] Ciampitti IA, Ciarlo EA, Conti ME. Nitrous oxide emissions from soil during soybean [(*Glycine max* (L.) Merrill] crop phenological stages and stubbles decomposition period. Biol Fertil Soils 2008;44(4):581–8.
[66] Aulakh MS, Walters DT. Crop residue type and placement effects on denitrification and mineralization. Soil Sci Soc Am 1991;55:1020–5.
[67] Crutzen PJ, Mosier AR, Smith KA, et al. N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmos Chem Phys 2008;8:389–95.
[68] UTN. Measurements from UTN for revision methodology nitrogen emissions from soybean cultivation in Argentina, received on 24 November 2008 from J. Hilbert (INTA-Argentina). 24 November 2008. Mendoza, Argentina; 2008.
[69] JRC. Well-to-wheel analysis of future automotive fuels and powertrains in the European context. European Council for Automative R&D (EUCAR), European Association for environment, health and safety in oil refining and distribution (CONCAWE), Institute for Environment and Sustainability of the EU Commission's Joint Research Centre (JRC/IES), Ispra, Italy; 2004.
[70] SAGPyA. Series historicas, Precios FOB oficiales, http://www.sagpya.gov.ar/new/0-0/nuevositio/agricultura/precios/series.php?fondo_agri_01=Precios&fondo_agri_precios=series. Secretaria de Agricultura, Ganadería, Pesca y Alimentos. Buenos Aires; 2008.
[71] Cramer J. and project group Sustainable Production of Biomass. Criteria for sustainable biomass production Final report of the Project group 'Sustainable production of biomass'. Energy Transition Task Force, The Hague; 2006. 40 p.
[72] ARB. Presentation on 'Low Carbon Fuel Standard Life Cycle Analysis (LCA) Working Group 1 Meeting' by Air Resources Board, January 17 2008. LCFS Lifecycle Analysis Working Group 1. Sacramento, California; 2008.
[73] WorldBank. Agro-industry animal feeds FAU 11. Finance and Agro Industry Unit Agriculture and Rural Development Department, World Bank; 1986.
[74] JRC. JRC updated biofuel pathways for Renewable Energy Directive as of 24 November 2008 (Excel Sheet). Joint Research Centre (JRC), European Commission, Brussels; 2008.
[75] Bertello F. Arrendamientos en el ciclo 2006/2007: ¿Quién paga más? Newspaper 'La Nación'. 5 March 2006. Buenos Aires, Argentina; 2006.
[76] Bertello F. Alzas del 10 y del 15% en los alquileres para el ciclo 2007/2008. Newspaper 'La Nación'. 7 July 2007. Buenos Aires, Argentina; 2007.
[77] Marelli F, Pristupluk R. Se profundiza la falta de productos en las góndolas. Newspaper 'La Nación'. 9 March 2008. Buenos Aires, Argentina; 2008.
[78] Viglizzo EF, Lertora F, Pordomingo AJ, et al. Ecological lessons and applications from one century of low external-input farming in the pampas of Argentina. Agric Ecosyst Environ 2001;83(1):65–81.
[79] Fernández OA Busso CA. Arid and semi-arid rangelands: two thirds of Argentina, Rala report No 200 Rangeland Desertification International Workshop. Iceland; 1997.
[80] Hilbert J.In: Presentation on 'technology aspects of bioenergy production in Argentina presented during Conference in London 2007, Rural Engineering Institute, INTA, Castelar, Buenos Aires; 2007.
[81] Sparovek G, Berndes G, Egeskog A, et al. Sugarcane ethanol production in Brazil: an expansion model sensitive to socioeconomic and environmental concerns. Biofuels Bioprod Biorefining 2007;1(4):270–82.
[82] Dornburg V, Faaij A, Verweij P, et al. Biomass Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy: Inventory and analysis of existing studies, supporting document. Utrecht University, University of Wageningen, ECN, VU Amsterdam, NEAA, ECN, performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change. (WAB); 2008.
[83] Dornburg V, Faaij A, Verweij P, et al. Climate change scientific assessment and policy analysis. Biomass Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy:

Inventory and analysis of existing studies. Supporting document, Report 500102 014. Utrecht University, Wageningen University, Netherlands Environmental Assessment Agency, Free University Amsterdam, ECN, UCE, performed within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB), Utrecht, the Netherlands; 2008.
[84] Berkum van S, Roza P, Pronk B. Sojahandel- en ketenrelaties: Aard en omvang van de internationale sojahandel- en ketenrelaties met speciale focus op Brazilie, Argentinie en Nederland. The Hague: Landbouw Economisch Instituut LEI; 2006.
[85] Stewart C. Introduction to high conservation values. In: GTZ Workshop on Biofuels and Certification on September 15, 2008; 2008.
[86] UNDP. Bioenergy primer—modernised biomass energy for sustainable development. New York: Bureau for Development Policy, United Nations Development Programme; 2000.
[87] Matteucci MD. Problemas ambientales en la Pampa Argentina. Buenos Aires: COCINET, Consejo Nacional de Investigaciones Científicas; 2000.
[88] Stewart BA, Wischmeier WH, Woolhiser DA. Control of water pollution from cropland: vol. 1, a manual for guideline development, vol. 2, an overview. USA: United States Department of Agriculture; 1975.
[89] Stone RP. Factsheet: universal soil loss equation (USLE). Ontario, Canada: Ministry of Agriculture, Food and Rural affairs; 2007.
[90] Nelson RG, Walsh M, Sheehan JJ. Methodology for estimating removable quantities of agricultural residues for bioenergy and bioproduct use, Applied biochemistry and biotechnology, Biotechnology for fuels and chemicals—the 25th symposium, al, Editor Humana Press; 2004. p. 13–26.
[91] AGSA. Predicting soil loss by water universal soil loss equation (USLE), http://www.uga.edu/agsa/ptpdf/USLEOutline.pdf. AGSA, Department of Crop and Soil Sciences or the University of Georgia; 2006.
[92] UIDAHO. Lecture environmental water quality BAE 452/552, session 14 erosion and sediment transport, loading calculations, http://www.agls.uidaho.edu/bae452-552/powerpoint%20pdfs/session14.pdf. Idaho: University of Idaho; 2008.
[93] Lesschen JP, Stoorvogel JJ, Smaling EMA, et al. A spatially explicit methodology to quantify soil nutrient balances and their uncertainties at the national level. Nutr Cycling Agroecosyst 2007;78(2):111–31.
[94] Sheldrick WF, Syers JK, Lingard J. A conceptual model for conducting nutrient audits at national, regional, and global scales. Nutr Cycling Agroecosyst 2002;62(1):61–72.
[95] Roy RN, Misra RV. Review on assessment of soil nutrient depletion and requirements—approach and methodology, available at: http://www.fao.org/Ag/agl/agll/nutrientmining/docs/AssessmentofSoilNutrientDepletion.pdf. Food and Agriculture Organization of the United Nations, Rome; 2003.
[96] Roy RN, Misra RV, Lesschen JP, et al. Assessment of soil nutrient balance: approaches and methodologies. Rome: Food and Agriculture Organization of the United Nations; 2003.
[97] Smeets E, Faaij A, Lewandowski I. The impact of sustainability criteria on the costs and potentials of bioenergy production. An exploration of the impact of the implementation of sustainability criteria on the costs and potential of bioenergy production, applied for case studies in Brazil and Ukraine, Report NWS-E-2005–6. Copernicus Institute—Department of Science, Technology and Society, commisioned by FAIR BIOTRADE project, Utrecht (103); 2005.
[98] DCA. Provincia de La Pampa—condiciones geotecnicas ambiente edafico, Principales Propiedades Químicas de los Suelos y sus Valores Críticos, http://www.mineria.gov.ar/estudios/dca/lapampa/AnexoIII_edaf.asp#t1. Datos de Calidad Ambiental, commisioned by Secretaría de Minería de la Nacion. Buenos Aires, Argentina; 2001.
[99] Kort J, Collins M, Ditsch D. A review of soil erosion potential associated with biomass crops. Biomass & Bioenergy 1998;4:351–9.
[100] Michelena RO Irurtia CB. La Siembra Directa controla la erosión y mejora la fertilidad del suelo Instituto de Suelos INTA Castelar, Buenos Aires; 2002.
[101] McLaughlin SB, Walsh ME. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass & Bioenergy 1998;14(4):317–24.
[102] Martellotto E, Salas H, Lovera E. El Monocultivo de Soja y la Sustentabilidad de la Agricultura Cordobesa. Buenos Aires: Estación Experimental Agropecuaria Manfred, Instituto Nacional de Tecnología Agropecuaria; 2001 .
[103] Galarza C, Gudelj V, Vallone P. Fertilización del Cultivo de Soja, Soja: Resultado de Ensayos de l Campaña 2000/2002 – part 2, Información para Extensión no.69, Estación Experimental Agropecuaria Marcos Juárez, Instituto Nacional de Tecnología Agropecuaria: Buenos Aires; 2001.
[104] Castino EG. Características y tendencias de uso de fertilizantes en Argentina para el cultivo de soja y su referencia en la región. 3 Congreso de Soja del Mercosur. Rosario: Mercosoja; 2006.
[105] Miles EE. Nutrientes: el costo del desbalance. Magazine 'Márgenes Agropecuarios' October, 2007;268:27–9.
[106] FAO/IIDS/NWRC (1999). CROPWAT 4 Windows 4.3, available on http://www.fao.org/nr/water/infores_databases_cropwat.html. Water Management and Irrigation Systems Group, Food and Agriculture Organization of the United Nations. Access date on 20 November 2008. Rome.
[107] Brouwer C. Chapter 3 Crop water needs. Part II. Determination of irrigation water needs, Irrigation Water Management: Irrigation Water Needs. Rome: Food and Agricultural Organization; 1986.
[108] Brouwer C, Heibloem M. Irrigation water management: irrigation water needs. Rome: United Nations Food and Agriculture Organization; 1986.
[109] FAO. Crop water information, http://www.fao.org/nr/water/cropinfo.html. Food and Agricultural Organization. Rome; 2008.
[110] Stroup JA, Sanderson J, Muir P, et al. Comparison of growth and performance in upland and lowland switchgrass types to water and nitrogen stress. Bioresour Technol 2003;86:65–72.
[111] De La Torre DG, He L, Jensen KL, et al. Estimating agricultural impacts of expanded ethanol production: policy implications for water demand and quality. In: Annual Meeting of the American Agricultural Economics Association; 2008.
[112] Yu G, Wang Q, Zhuang J. Modeling the water use efficiency of soybean and maize plants under environmental stresses: application of a synthetic model of photosynthesis-transpiration based on stomatal behavior. J Plant Physiol 2004;(161):303–18.
[113] Berndes G. Bioenergy and water—the implications of large-scale bioenergy production for water use and supply. Glob Environ Change 2002;12(4):253–71.
[114] Jørgensen U, Schelde K. Energy crop water and nutrient use efficiency, prepared for the IEA Bioenergy Task 17, Short rotation Crops. Tjele, Denmark: Danish Institute of Agricultural Sciences, Department of Crop Physiology and Soil Science, Research Centre, Foulum; 2001.
[115] van Keulen H, van Laar HH. The relation between water use and crop production, modelling of agricultural production: weather, soils and crops, Wageningen; 1986. p. 117–29.
[116] APA. Creación de la Administración Provincial del Agua: Ley 773 describes the creation and tasks of the Provincal Water management, which includes the conservation and preservation of its water resources. Gobierno de la Provincia; 1977: 773.2 p.
[117] APA. Régimen de conservación y uso de Agua Potable: Law 1.027/80 regulates the conservation and use of drinking water in the province Boletín Oficial gobierno de de la Provincia de La Pampa. NJF N. 1027/80 (Ley 1.027); 1980. 2 p.
[118] APA. Normas sobre emisión o descarga al ambiente de efluentes líquidos y sus agregados: Ley 1508 regulates the norms for emission or loading of liquid fluids and its aggregates to the environment. La Camara de Diputados de La Provincia de La Pampa. 1508; 1993. 2 p.
[119] Hall RL. Grasses for energy production—hydrological guidelines, B/CR/00783/GUIDELINES/GRASSES/URN 03/882. DTI New and Renewable Energy Programme; 2003.
[120] SAGPyA. Estimaciones agrícolas, informes por cultivo, http://www.sagpya.mecon.gov.ar/. Secretaria de Agricultura, Ganadería, Pesca y Alimentos de la Republica Argentina Buenos Aires; 2007.
[121] Petruzzi H. Personal communication with H. Petruzzi on Switchgrass production in Argentina based on field experiment INTA Anguil. 14 september 2007. Anguil; 2007.
[122] Sinclair TR, Salvado-Navarro LR, Salas G, et al. Soybean yields and soil water status in Argentina: simulation analysis. Agric Syst 2007;94(2):471–7.
[123] Lewandowski I, Scurlock JM, Lindvall E, et al. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. Biomass & Bioenergy 2003;25(4):335–61.
[124] McLaughlin S, Bouton J, Bransby D, et al. Developing switchgrass as a bioenergy crop, Perspectives on new crops and new uses, Janick, Editor Alexandria, VA, USA; 1999.
[125] Bessembinder JJE, Leffelaar PA, Dhindwal AS, et al. Which crop and which drop, and the scope for improvement of water productivity. Agric Water Manage 2003;73:113–30.
[126] Sinclair TR, Farias JR, Neumaier N, et al. Modeling nitrogen accumulation and use by soybean. Field Crops Res 2003;81(2):149–58.
[127] León I. Contaminación de aguas subterráneas con fertilizantes y agroquímicos, available at http://www.lapampa.gov.ar/RecHidricos/Publicaciones/Libro_Primer_Congreso_del_Agua.pdf. Primer Congreso Pampeano del agua. Santa Rosa: Consejo Asesor en Recursos Hídricos del Gobierno de La Pampa; 2005.
[128] van Berkum S. Sojahandel-en ketenrelaties: Aard en omvang van de internationale sojahandel- en ketenrelaties met speciale focus op Brazilie, Argentinie en Nederland. The Hague: LEI; 2006.
[129] Dow Agrosciences. Material safety data sheet Lorsban 75 WG, available at: http://www.hort.wisc.edu/cran/mgt_articles/articles_pest_mgt/labels_msds/labels/lorsban%2075wg.pdf; 2004.
[130] PPBD. The footprint PPDB, pesticide properties database, available at: http://sitem.herts.ac.uk/aeru/footprint/index.htm. University of Hertfordshire, EU-Funded Footh print project. UK 13 December 2008; 2008.
[131] NPIC. National pesticide information center, http://npic.orst.edu/ppdmove.htm. Oregon State University, United States Environmental Protection Agency. 13 December 2008. Corvallis, USA; 2008.
[132] Gobierno. Disposiciones para la Preservación del Recurso Aire: Law 20284 regulates the jurisdiction and organization of national and provincial authorities to control and implement the norms for atmospheric contaminants Boletín Oficial del 03/05/1973 Secretaría de Ambiente y Desarrollo Sustentable (20284); 1973.
[133] Gobierno. Residuos Peligrosos: Law 20541 regulates the transport, treatment and disposal of dangerous waste to avoid (amongst others) contamination of air Boletín Oficial del 17/01/1992 – El Senado y Cámara de Diputados de la Nación Argentina. (24051); 1991.
[134] DCA. Provincia de La Pampa – calidad del aire, available at: http://www.mineria.gov.ar/estudios/dca/lapampa/l-6.asp#14. La Secretaría de Minería del

Ministerio de Planificación Federal, Inversión Pública y Servicios Buenos Aires; 2001.
[135] Wicke B. The socio-economic impacts of large-scale land use change and export-oriented bio-energy production in argentina; quantifying the direct, indirect and induced impacts of agricultural intensification and bio-energy production with input–output analysis, Department of Science, Technology and Society, 2006, Copernicus Institute, University Utrecht: Utrecht (106); 2006.
[136] Llach JJ, Harriaque MM, O'Connor E., La generación de empleo en las cadenas agroindustriales, available at: http://www.producirconservando.org.ar/docs/servicios/framset_servicios.htm. Fundación Producir Conservando, Buenos Aires; 2004.
[137] Ministerio de Economía. Matriz Argentina de Insumo-Producto 1997, available at: http://www.francomanopicardi.com.ar/news/004_abril2008/04_21al25/03_agricultura_ACSOJA_ImportanciaEconomica.htm#_ftn1. ACSOJA (Asociación de la Cadena de la Soja Argentina). November 2008. Buenos Aires; 1997.
[138] Télam. Pronostican un fuerte crecimiento en la producción de biodiesel, http://www.concienciarural.com.ar/articulos/informacion-general/pronostican-para-el-2008-un-fuerte-crecimiento-en-la-produccion-de-biodiesel/art286.aspx. Télam/Infocampo 21 January 2008; 2008.
[139] ACSOJA. La importancia económica de la soja, available at: http://www.francomanopicardi.com.ar/news/004_abril2008/04_21al25/03_agricultura_ACSOJA_ImportanciaEconomica.htm. Asociación de la Cadena de la Soja Argentina. 23 November 2008. Rosario; 2008.
[140] Mathews JA, Goldsztein H. Capturing late comer advantages in the adoption of biofuels: The case of Argentina. Energy Policy 2009;37(1):326–37.
[141] OHCHR-UNOG. The international bill of human rights, available on: http://www.unhchr.ch/html/menu6/2/fs2.htm. 23 November 2008. Geneva; 1996.
[142] Tomada CA. Statement of Argentina in high-level roundtable on employment and industrial relations: promoting responsible business conduct in a globalising economy. OECD – ILO High-Level Roundtable on Employment and Industrial Relations: Promoting Responsible Business Conduct in a Globalising Economy. OECD-ILO. Paris, France; 2008.
[143] OECD. The OECD guidelines for multinational enterprises: text, commentary and clarifications, DAFFE/IME/WPG (2000)15/FINAL. Directorate for financial, fiscal and enterprise affairs, Committee on International Investment and Multinational Enterprises, Organisation for Economic Co-operation and Development; 2001.
[144] Brondo A, Luparia C. La libreta del trabajador rural, Trabajo de campo: producción, technología y empleo en el medio rural, Neimanl, Editor Ciccus: Buenos Aires; 2001.
[145] Neiman G. Los salarios de los trabajadores comprendidos en el regimen nacional de trabajo agrario. International Labour Institute (ILO); 2003.
[146] Lema D. El papel de los contratos de arrendamiento, a sintesis from the report of Tenencia de la Tierra, Contratos y Uso de Recursos en la Producción Agrícola Pampeana: Teoría y Evidencia''. Instituto de Economía y Sociología, INTA, Buenos Aires; 2004.
[147] Adámoli J. Evaluación Regional del Impacto de Sustentabilidad de la cadena productiva de la soja. Taller Nacional ''Sustentabilidad de la Cadena Productiva de la Soja Argentina y la Región''. Buenos Aires: Fundación Ambiente y Recursos Naturales; 2007.
[148] Huergo HA. OPINION: Los temas de la semana: Nuevo escenario para el sector agropecuario, Carta abierto al ministro Lousteau. Newspaper 'Clarin'. 15 March 2008. Buenos Aires; 2008.
[149] ISAAA. Aumentan los cultivos transgénicos. Informativo Semanal Bolsa de Comercio de Rosario February 2008; 2008: 26, 1346, p.1–2.
[150] AAPRESID. Brochure on 'La evolución de la Siembra Directa', Agricultura Certificado. AAPRESID, Rosario; 2008.
[151] Panichelli L. Certificación de producción sustentable de biocombustibles: consecuencias para la Argentina. Magazine 'Agromercado' 2007;(October):270.